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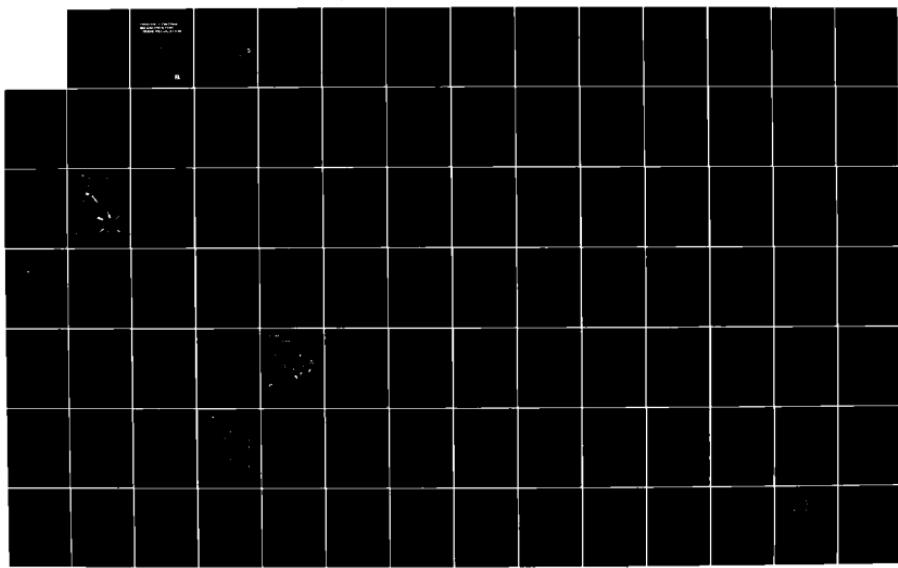
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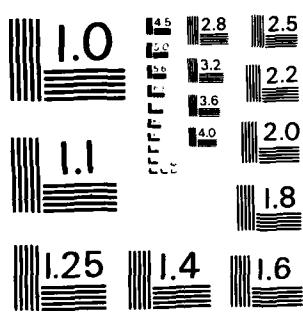
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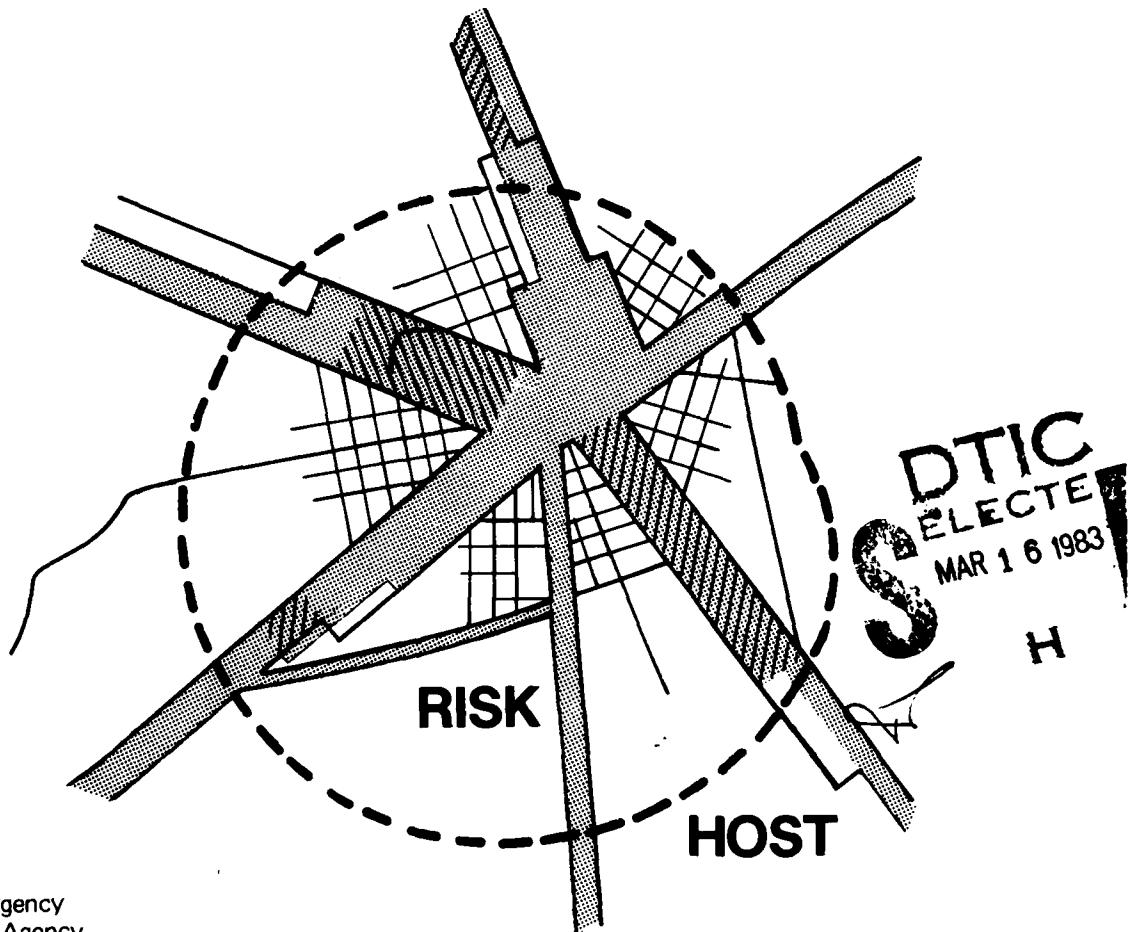
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FINAL REPORT

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TRAFFIC CONTROL MEASURES FOR CRISIS RELOCATION

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For
Federal Emergency
Management Agency
Washington, D.C. 20472

Contract EMW-C-0679
Work Unit 2311E

January 1983

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Final Report

TRAFFIC CONTROL MEASURES FOR
CRISIS RELOCATION

by

John W. Billheimer
Juliet McNally

for

Federal Emergency Management Agency
Washington, D.C. 20472

Contract No. EMW-C-0679



January 1983

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EXECUTIVE SUMMARY

INTRODUCTION

This report augments past investigations of emergency transportation by addressing the specific traffic control problems likely to arise under crisis relocation conditions, investigating control options designed to alleviate these problems, and developing guidance for public safety agencies charged with maintaining orderly traffic flows during evacuations. Potentially useful traffic control procedures have been analyzed through a combination of mathematical analysis, planning reviews, and intensive interviews with planners and public safety personnel experienced in controlling significant volumes of traffic under both normal and emergency conditions.

OVERVIEW

The capacity of most regional road networks will be severely taxed by the relocation effort. Bottlenecks are likely to develop on narrow rural roads outside city limits. If an initial rush to evacuate the city causes severe congestion to develop behind these bottlenecks, the success of the entire relocation plan will be threatened. Although many of the potential road capacity problems may be solved through careful advance planning and rigorous control efforts, planners must recognize that rated road capacities are not likely to be attainable for twenty-four hours per day, and that severe peaks in travel patterns may be expected, particularly on the first day of relocation. Assumptions of smooth flow over a three-day period will result in overly optimistic and potentially disastrous assessments of road network capacities.

CONTROL MEASURES

Exhibit S.1 lists a number of traffic planning and control measures that might be employed under crisis relocation conditions for such key activities as:

- Route Assignment;
- Departure Scheduling;
- Road Capacity Expansions;
- Entry Control for Outbound Routes;

Exhibit S.1

TRAFFIC CONTROL MEASURES
FOR CRISIS RELOCATION

CONTROL ACTIVITY	CONVENTIONAL MEASURES (To be applied in all instances)	CONTINGENT MEASURES (To be considered only if conventional measures prove inadequate)	CONTRAPRODUCTIVE MEASURES (To be avoided)
ROUTE ASSIGNMENT	ALWAYS <ul style="list-style-type: none"> • Use all available outbound routes • Balance flows to minimize clearance time • Inspect all evacuation routes • Develop contingency plans • Provide clear instructions 	SOMETIMES <ul style="list-style-type: none"> • Revise risk/host assignments • Redefine risk areas 	NEVER <ul style="list-style-type: none"> • Discourage individuals with personal host-area destinations • Develop route assignments requiring individual vehicle inspection
DEPARTURE SCHEDULING	<ul style="list-style-type: none"> • Broadcast traffic information • Encourage off-peak departures • Operate support services around the clock • Schedule departures of autoless and critical workers 	<ul style="list-style-type: none"> • Schedule departure of all risk-area residents on geographic basis (begin with densely populated core and work outward) 	<ul style="list-style-type: none"> • Prepare off-again, on-again schedules with short time frames (i.e. hour-by-hour) • Use arbitrary scheduling rules (i.e. even/odd license plates) • Develop schedules requiring individual vehicle inspection
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ENTRY CONTROL FOR OUTBOUND ROUTES	<ul style="list-style-type: none"> • Identify key control points • Assign officers to key merging points • Use barricades of heavy equipment where necessary to deny access and force geographic schedules 	<ul style="list-style-type: none"> • Stationing police officers at barricades • Using police officers to meter flow of freeway entrance ramps 	<ul style="list-style-type: none"> • Use moveable barricades (i.e. saw horses or cones) without police presence • Establish permit systems requiring individual vehicle inspection
PERIMETER CONTROL ON INBOUND ROUTES	<ul style="list-style-type: none"> • Establish control points on all routes <ul style="list-style-type: none"> – at host/risk boundary – at host-area outskirts • Lay out ample holding areas adjacent to control points • Intercept and interrogate all inbound traffic 		<ul style="list-style-type: none"> • Use road shoulders for holding-area parking
FLOW MAINTENANCE	<ul style="list-style-type: none"> • Prepare personnel deployment plans • Undertake dynamic surveillance of traffic patterns and redirect flow accordingly • Patrol all segments of evacuation routes (particularly bottleneck sections) • Respond to all incidents, clearing stalled and disabled vehicles and reinstating flow as soon as possible 		<ul style="list-style-type: none"> • Stop traffic flow to answer individual questions or redirect misrouted vehicles
DESTINATION CONTROL	<ul style="list-style-type: none"> • Review host area parking plans • Direct vehicle flows to parking areas • Supervise parking activities 		<ul style="list-style-type: none"> • Allow parking queues to back up onto evacuation routes

- Perimeter Control on Inbound Routes;
- Flow Maintenance; and
- Destination Control.

The exhibit segregates control measures for these activities into three categories:

1. CONVENTIONAL MEASURES which should always be employed in crisis relocation
2. CONTINGENT MEASURES which should be considered only if conventional measures prove inadequate; and
3. CONTRAPRODUCTIVE MEASURES which should be avoided at all costs.

Route Assignments

Successful routing strategies should attempt to minimize the time required to clear the risk area and must reflect bottleneck locations, roadway capacities, risk/host assignments, and the use of roadways by adjacent risk areas. All available outbound routes should be used; routes should be inspected prior to use, and contingency plans should be developed in advance to deal with potential tie-ups on any single route. Although these admonitions seem obvious, they have not always been followed, either in planning or in practice, in emergency evacuations. Evacuees having their own personal destination for relocation should be accommodated to the maximum extent possible, and planners should avoid routing assignments which require individual vehicle inspection.

Departure Scheduling

In most risk areas, it is imperative that measures be adopted to persuade evacuees to stagger their departure times, thereby limiting the number of vehicles on the road at any given time and minimizing the possibility of severe congestion. One of the most important means of influencing departure times and travel patterns will be the frequent broadcasting of information regarding traffic conditions on outbound routes. Such reports also serve to advise motorists of traffic tie-ups and alternative route choices. Other indirect means of persuading evacuees to smooth their departure times and limit congestion include suggesting off-peak departure times; advising that families take only one automobile to the host area; and operating support services around the clock.

Historical evidence of people's behavior in the face of evacuation orders suggests that more direct measures may be needed to schedule

departures in many U.S. cities. Relatively few residents of hurricane-threatened sections of the gulf coast or residents of other areas threatened by hazardous spills have required more than ten hours to vacate risk areas in response to evacuation orders. Yet only two of nine cities whose evacuation plans were studied in detail could be cleared of evacuees within ten hours.

In cases in which departure times must be directly and rigorously scheduled to avoid severe congestion, schedules should be developed for different geographic groups within the risk area. Such geographically-based schedules can be enforced effectively through such mechanisms as freeway ramp closures and barricades at entry points to evacuation routes. Initial access to evacuation routes should be granted to those population clusters deemed to be most "at risk" (i.e., the densest population clusters near the center of large cities or the residents living nearest a military target). In subsequent six-to-twelve-hour time periods, geographic areas to be relocated would gradually fan out to encompass the entire risk area. This system of staged departures was used effectively in evacuating 217,000 residents of the Toronto suburb of Mississauga within 24 hours of the derailment of a chlorine tank in November, 1979.

Scheduling rules using such mechanisms as license plates or telephone prefixes should be avoided. Besides requiring individual vehicle inspection--with attendant traffic tie-ups--they have the severe drawback of being obviously arbitrary. Such arbitrary rules are not likely to be perceived as being reasonable or fair in life-threatening circumstances, and, consequently, are not likely to be widely respected or observed.

Road Capacity Expansion

Although the capacities of particular roadways under normal conditions of peak commuting traffic are well-documented, few empirical guidelines exist for estimating road capacity under the stressful conditions likely to accompany crisis relocation. Accidents, stalled vehicles, and anxiety are likely to reduce roadway capacity for significant periods of time. In addition to accident-related stoppages, freeway flow can break down completely if entering vehicles cause the capacity of the roadway to be exceeded for significant periods of time. In the face of the uncertainties associated with traffic flow under crisis relocation conditions, SYSTAN and other FEMA researchers have insisted that conservative safety factors be applied to rated highway capacity figures when planning for crisis relocation. Quantitative support for this position was obtained from employees of the California Department of Transportation (CALTRANS) as part of the current study. In monitoring the behavior of weekend drivers unfamiliar with the congested freeways in the vicinity of special events and resort areas, CALTRANS' employees have found that the average freeway flow is 1,500 vehicles per lane per hour, considerably lower than the rated capacity of 2,000 vehicles per hour measured under daily commuting conditions.

Several measures should always be employed to increase the carrying capacity of evacuation routes. These include the use of shoulders, signal timing, effective signing and striping, and insistence that households use only a single auto in relocating. The establishment of wrong-way flow on routes on which contraflow procedures are not generally used represents a difficult, time-consuming, and potentially dangerous departure from conventional procedures. Wrong-way flow should be considered seriously only by cities which will require more than 24 hours to clear their risk areas using existing outbound lanes and which are willing to develop and enforce rigid departure schedules. The establishment of wrong-way flow will generally require that some population groups--probably residents of outlying suburbs--delay their departures while reverse-flow lanes are set up.

Entry Control for Outbound Routes

Traffic entering the main evacuation routes will almost certainly need to be regulated to maximize outbound flow. The most effective and efficient means for regulating entry to evacuation routes is to block key intersections and freeway entrance ramps temporarily with large vehicles such as trucks or trailers. Public safety personnel may remove those barriers in response to changing traffic conditions or published departure schedules. Where continuous monitoring and metering of flow is desired, police officers should be placed at key intersections and on-ramps to make sure that traffic streams merge efficiently and that flow levels do not approach critical densities. Key control points should be identified in advance by traffic engineers and public safety officials.

Perimeter Control on Inbound Routes

Emergency traffic control posts and ample off-road holding areas need to be established along inbound routes to seal off the risk areas and ensure that entry is restricted to authorized vehicles. The posts will be staffed with police officers and auxiliary personnel who will interrogate drivers of vehicles, examine and issue road-use permits, & direct inbound traffic. During the first few days of the relocation period, control posts and holding areas should be established along major routes at the far outskirts of host areas as well as at the boundaries separating risk and host areas. These outlying control points will form the first line of defense against inbound traffic and are necessary to avoid further overloading outbound streams of evacuation traffic with inbound vehicles turned back at the risk-area boundaries.

Flow Maintenance

It is imperative that public safety officers keep traffic moving during crisis relocation. Slowdowns and stoppages require immediate police attention and control if a continuous flow of traffic is to be maintained. Stalled and disabled vehicles must be immediately moved off the traveled way. Officers should focus their attention on the bottleneck segments of evacuation routes, since any reduction of capacity along these segments will directly affect the time required to clear the risk area. Critical segments of roadway should be kept under continuous aerial surveillance, and flows should be redirected as problems develop on some routes and unused capacity appears on others.

Destination Control

One aspect of crisis relocation which is often overlooked is the importance of adequate traffic control measures at host-area destinations. It is essential that ample off-highway parking be provided near reception and care centers. In addition to parking lots, nearby fields and other suitable spaces should be striped to accommodate the efficient parking of arriving vehicles. Under no circumstances should queues of arriving vehicles be allowed to extend backward onto main evacuation routes. This possibility affords more of a threat to the limited highway capacity in most host areas than the possibility of stalled vehicles or accidents, and will be harder to correct if it does occur.

THE ROLE OF PUBLIC SAFETY PERSONNEL

A separate, stand-alone appendix to this volume, entitled "Crisis Relocation Guidelines for Public Safety Agencies," outlines the role of public safety personnel in implementing the desirable control strategies identified in Summary Exhibit S.1, presents planning factors for determining basic staffing levels, and explores alternatives for reducing the personnel levels required for emergency traffic control. The national availability of uniformed law enforcement personnel is 2.1 officers per thousand residents (3.3 officers per thousand residents in cities over 250,000). It seems clear from the developed guidelines, past emergencies, and experience with the control of large volumes of traffic at special events that the need for experienced police officers during evacuation is certain to exceed the number of personnel available locally. It is essential, therefore, that public safety officials set clear priorities on the tasks to be assigned under crisis relocation conditions. Traffic control priorities must be established locally to fit local conditions, but certain general principles should be observed:

1. Surveillance and control of bottleneck areas on outbound evacuation routes is of predominant importance. In addition, enough traffic control personnel must be assigned to host-area

destinations to make sure that arriving traffic does not back up onto the evacuation route.

2. The lowest order of priority should generally be assigned to traffic control on collector streets within the risk area. These streets will generally have sufficient capacity, and local congestion is not likely to affect the flow along critical outbound routes.
3. Perimeter control of inbound traffic is certain to be of less immediate importance than the maintenance of outbound flow. Some perimeter control tasks, such as driver interrogation and permit issuance, may be handled by volunteers or auxiliary personnel.

ADDITIONAL AREAS OF INVESTIGATION

The current study has highlighted several areas in which the existing level of understanding of traffic control measures needs to be expanded for crisis relocation planning. Topics which should be investigated include:

- Investigations of Road Capacity Under the Unfamiliar, Stressful Conditions Accompanying Crisis Relocation;
- Exploration of the Applicability of Computer Simulation Models to Large-Scale Evacuation Planning;
- Special Studies in Large Risk Areas; and
- Preparation of Simplified Transportation Planning Guidelines.



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PREFACE AND ACKNOWLEDGEMENTS

This report augments past studies of emergency transportation by addressing the specific traffic control problems likely to arise under crisis relocation conditions, investigating control options designed to alleviate these problems, and developing guidance for public safety agencies charged with maintaining orderly traffic flows during evacuations.

The report has been prepared in the Los Altos, California offices of SYSTAN, Inc. under Contract Number EMW-C-0679 with the Federal Emergency Management Agency. Dr. John Billheimer of SYSTAN was the project leader and principal author of the report. Ms. Juliet McNally assisted with all phases of the study, while Ms. Gigi Gillson and Ms. Ana Chou helped to prepare the final report. Mr. Stephen Birmingham and Mr. James Jacobs acted as technical monitors for the Federal Emergency Management Agency.

The study has benefited enormously from the insights of numerous planners and public safety personnel experienced in controlling significant volumes of traffic under both normal and emergency conditions. A partial list of those deserving acknowledgement for their contribution appears below.

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Lt. William Russell

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Charles Gunn

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Region X
Mr. Frank Mollner,
Region VIII

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CALIFORNIA (Berkeley)
Institute for Traffic
& Transportation
Studies
Professor Adolf May

A separate appendix entitled "Crisis Relocation Guidelines for Public Safety Agencies" summarizes emergency traffic control measures, lists the responsibilities of public safety agencies, and provides staffing guidance for public safety personnel charged with traffic control duties during crisis relocation.

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In most risk areas, it is imperative that measures be adopted to persuade evacuees to stagger their departure times, thereby limiting the number of vehicles on the road at any given time and minimizing the possibility of severe congestion. One of the most important means of influencing departure times and travel patterns will be the frequent broadcasting of information regarding traffic conditions on outbound routes. Such reports also serve to advise motorists of traffic tie-ups and alternative route choices. Other indirect means of persuading evacuees to smooth their departure times and limit congestion include suggesting off-peak departure times; advising that families take only one automobile to the host area; and operating support services around the clock.

Historical evidence of people's behavior in the face of evacuation orders suggests that more direct measures may be needed to schedule

departures in many U.S. cities. Relatively few residents of hurricane-threatened sections of the gulf coast or residents of other areas threatened by hazardous spills have required more than ten hours to vacate risk areas in response to evacuation orders. Yet only two of nine cities whose evacuation plans were studied in detail could be cleared of evacuees within ten hours.

In cases in which departure times must be directly and rigorously scheduled to avoid severe congestion, schedules should be developed for different geographic groups within the risk area. Such geographically-based schedules can be enforced effectively through such mechanisms as freeway ramp closures and barricades at entry points to evacuation routes. Initial access to evacuation routes should be granted to those population clusters deemed to be most "at risk" (i.e., the densest population clusters near the center of large cities or the residents living nearest a military target). In subsequent six-to-twelve-hour time periods, geographic areas to be relocated would gradually fan out to encompass the entire risk area. This system of staged departures was used effectively in evacuating 217,000 residents of the Toronto suburb of Mississauga within 24 hours of the derailment of a chlorine tank in November, 1979.

Scheduling rules using such mechanisms as license plates or telephone prefixes should be avoided. Besides requiring individual vehicle inspection--with attendant traffic tie-ups--they have the severe drawback of being obviously arbitrary. Such arbitrary rules are not likely to be perceived as being reasonable or fair in life-threatening circumstances, and, consequently, are not likely to be widely respected or observed.

Road Capacity Expansion

Although the capacities of particular roadways under normal conditions of peak commuting traffic are well-documented, few empirical guidelines exist for estimating road capacity under the stressful conditions likely to accompany crisis relocation. Accidents, stalled vehicles, and anxiety are likely to reduce roadway capacity for significant periods of time. In addition to accident-related stoppages, freeway flow can break down completely if entering vehicles cause the capacity of the roadway to be exceeded for significant periods of time. In the face of the uncertainties associated with traffic flow under crisis relocation conditions, SYSTAN and other FEMA researchers have insisted that conservative safety factors be applied to rated highway capacity figures when planning for crisis relocation. Quantitative support for this position was obtained from employees of the California Department of Transportation (CALTRANS) as part of the current study. In monitoring the behavior of weekend drivers unfamiliar with the congested freeways in the vicinity of special events and resort areas, CALTRANS' employees have found that the average freeway flow is 1,500 vehicles per lane per hour, considerably lower than the rated capacity of 2,000 vehicles per hour measured under daily commuting conditions.

Several measures should always be employed to increase the carrying capacity of evacuation routes. These include the use of shoulders, signal timing, effective signing and striping, and insistence that households use only a single auto in relocating. The establishment of wrong-way flow on routes on which contraflow procedures are not generally used represents a difficult, time-consuming, and potentially dangerous departure from conventional procedures. Wrong-way flow should be considered seriously only by cities which will require more than 24 hours to clear their risk areas using existing outbound lanes and which are willing to develop and enforce rigid departure schedules. The establishment of wrong-way flow will generally require that some population groups--probably residents of outlying suburbs--delay their departures while reverse-flow lanes are set up.

Entry Control for Outbound Routes

Traffic entering the main evacuation routes will almost certainly need to be regulated to maximize outbound flow. The most effective and efficient means for regulating entry to evacuation routes is to block key intersections and freeway entrance ramps temporarily with large vehicles such as trucks or trailers. Public safety personnel may remove those barriers in response to changing traffic conditions or published departure schedules. Where continuous monitoring and metering of flow is desired, police officers should be placed at key intersections and on-ramps to make sure that traffic streams merge efficiently and that flow levels do not approach critical densities. Key control points should be identified in advance by traffic engineers and public safety officials.

Perimeter Control on Inbound Routes

Emergency traffic control posts and ample off-road holding areas need to be established along inbound routes to seal off the risk areas and ensure that entry is restricted to authorized vehicles. The posts will be staffed with police officers and auxiliary personnel who will interrogate drivers of vehicles, examine and issue road-use permits, & direct inbound traffic. During the first few days of the relocation period, control posts and holding areas should be established along major routes at the far outskirts of host areas as well as at the boundaries separating risk and host areas. These outlying control points will form the first line of defense against inbound traffic and are necessary to avoid further overloading outbound streams of evacuation traffic with inbound vehicles turned back at the risk-area boundaries.

Flow Maintenance

It is imperative that public safety officers keep traffic moving during crisis relocation. Slowdowns and stoppages require immediate police attention and control if a continuous flow of traffic is to be maintained. Stalled and disabled vehicles must be immediately moved off the traveled way. Officers should focus their attention on the bottleneck segments of evacuation routes, since any reduction of capacity along these segments will directly affect the time required to clear the risk area. Critical segments of roadway should be kept under continuous aerial surveillance, and flows should be redirected as problems develop on some routes and unused capacity appears on others.

Destination Control

One aspect of crisis relocation which is often overlooked is the importance of adequate traffic control measures at host-area destinations. It is essential that ample off-highway parking be provided near reception and care centers. In addition to parking lots, nearby fields and other suitable spaces should be striped to accommodate the efficient parking of arriving vehicles. Under no circumstances should queues of arriving vehicles be allowed to extend backward onto main evacuation routes. This possibility affords more of a threat to the limited highway capacity in most host areas than the possibility of stalled vehicles or accidents, and will be harder to correct if it does occur.

THE ROLE OF PUBLIC SAFETY PERSONNEL

A separate, stand-alone appendix to this volume, entitled "Crisis Relocation Guidelines for Public Safety Agencies," outlines the role of public safety personnel in implementing the desirable control strategies identified in Summary Exhibit S.1, presents planning factors for determining basic staffing levels, and explores alternatives for reducing the personnel levels required for emergency traffic control. The national availability of uniformed law enforcement personnel is 2.1 officers per thousand residents (3.3 officers per thousand residents in cities over 250,000). It seems clear from the developed guidelines, past emergencies, and experience with the control of large volumes of traffic at special events that the need for experienced police officers during evacuation is certain to exceed the number of personnel available locally. It is essential, therefore, that public safety officials set clear priorities on the tasks to be assigned under crisis relocation conditions. Traffic control priorities must be established locally to fit local conditions, but certain general principles should be observed:

1. Surveillance and control of bottleneck areas on outbound evacuation routes is of predominant importance. In addition, enough traffic control personnel must be assigned to host-area

destinations to make sure that arriving traffic does not back up onto the evacuation route.

2. The lowest order of priority should generally be assigned to traffic control on collector streets within the risk area. These streets will generally have sufficient capacity, and local congestion is not likely to affect the flow along critical outbound routes.
3. Perimeter control of inbound traffic is certain to be of less immediate importance than the maintenance of outbound flow. Some perimeter control tasks, such as driver interrogation and permit issuance, may be handled by volunteers or auxiliary personnel.

ADDITIONAL AREAS OF INVESTIGATION

The current study has highlighted several areas in which the existing level of understanding of traffic control measures needs to be expanded for crisis relocation planning. Topics which should be investigated include:

- Investigations of Road Capacity Under the Unfamiliar, Stressful Conditions Accompanying Crisis Relocation;
- Exploration of the Applicability of Computer Simulation Models to Large-Scale Evacuation Planning;
- Special Studies in Large Risk Areas; and
- Preparation of Simplified Transportation Planning Guidelines.

1. INTRODUCTION

1.1 BACKGROUND

The current civil preparedness program of the Federal Emergency Management Agency (FEMA) includes two basic strategies for protecting the American population against nuclear attack: the first is to provide the best protection possible at or near homes, schools, and places of work for protection if the population is kept essentially in place; the second is to require people to leave threatened areas for refuge in safer places. Both strategies are important, because suitable options are needed to meet particular situations as they develop.

Five primary arguments support the need to provide an evacuation capability through crisis relocation planning:

- It is likely that a nuclear attack upon the United States will be preceded by a crisis buildup of sufficient duration to permit population relocation from high-risk areas;
- If an adversary's cities were to be evacuated during a period of crisis, the United States cities should also be evacuated;
- It is likely that many citizens will leave large cities in the face of crisis in a "spontaneous evacuation" whether or not they are advised to do so;
- Crisis evacuation has proven feasible in the face of recent large-scale disasters such as hurricane warnings; and
- Given the current availability and location of shelter space, studies have shown that a strategy of population relocation could save far more lives than reliance on in-place protection.

Population evacuation is not new. For centuries, cities and other communities have been evacuated to escape natural disasters and invading armies. Most evacuations have been spontaneous and disorganized. In 1865, Leo Tolstoy wrote the following about the evacuation of Moscow ahead of Napoleon's army:

"This event - the abandonment...of Moscow - was...inevitable after the battle of Borodino...Every Russian might have predicted it, not by reasoning things out but by hearkening to the sentiment inherent in each of us and in our forefathers...As the enemy drew near, the well-to-do elements of the population departed, abandoning their possessions, while the poorer classes remained..." (Reference H-13)

Today population centers are much larger and more densely populated than in the past. Thus if our cities are to be evacuated, we not only need to use all of the technological resources available to us, we must also be prepared with detailed plans that reflect an accurate understanding of all of the important phenomena that will influence mass movement of people under stress.

The movement of large population masses in advance of a threatened attack will severely test national and local transportation resources. Plans for evacuating populations, maintaining essential governmental and private services, and transporting critical workers all hinge on the availability, maintenance, and control of the nation's fuel resources, transportation fleet, and road and rail networks. Past research has assessed the transportation requirements accompanying crisis relocation, identified promising means for reconfiguring the transportation and fuel supply networks to meet these requirements, and developed and documented guidelines for providing transportation support for the crisis relocation strategy (References A-1 and A-2).

If the concept of crisis relocation is to succeed, it is imperative that traffic flows on the nation's road network be controlled effectively throughout the relocation period. Many activities can help to maintain an uninterrupted flow of traffic during this period:

"Vehicle movements must be scheduled, monitored, and controlled on all evacuation routes. Highway patrol and emergency road rescue services must be used effectively to prevent congestion and to remove disabled vehicles. A surveillance and communication system must be set up to issue operating instructions for vehicle control. In the absence of effective planning and control, monumental traffic jams will develop, accidents will compound congestion, vehicles will be abandoned, relocation routes and destinations will be altered, panic is likely, and the relocation effort will be doomed to failure." (Reference A-1)

1.2 OBJECTIVE

The current study augments past investigations of emergency transportation by addressing the specific traffic control problems likely to arise under crisis relocation conditions, investigating control options designed to alleviate these problems, and developing guidance for public safety agencies charged with maintaining orderly traffic flows during crisis relocation.

1.3 APPROACH

To achieve the above objective, a two-pronged research approach has been followed, consisting of (1) detailed analysis and modeling of traffic control procedures; and (2) intensive interviews with planners and public safety personnel experienced in controlling significant volumes of traffic under both normal and emergency conditions.

1.3.1 Analysis of Traffic Control Procedures

Traffic control procedures investigated in detail included techniques for:

- routing vehicles;
- scheduling departures;
- expanding the capacity of existing roadways through such measures as
 - shoulder use
 - signing and striping
 - signal timing
 - minimum occupancy restrictions, and
 - wrong-way flows;
- regulating flow of outbound traffic onto evacuation routes;
- controlling the flow of inbound traffic at the perimeters of the risk area; and
- maintaining traffic flows through bottlenecks by
 - dynamic surveillance
 - prompt incident response
 - emergency patrols, and
 - destination area controls.

In addition to investigating detailed traffic control procedures, a range of different cities were surveyed to determine the number of available routes and the congestion conditions likely to occur under crisis relocation conditions. The transportation portions of crisis relocation plans for cities of different sizes were examined (References B-1 through B-8), road capacities were compared with projected evacuation loadings, and general guidelines were developed for those conditions under which different control strategies should be attempted.

1.3.2 Interviews with Planners and Public Safety Personnel

Planners and public safety personnel interviewed in the course of the study included police officials with direct responsibility for recent evacuations (i.e., Mississauga, Ontario--References D-1 through D-8, and the Texas Gulf Coast--Reference H-6); planners with the responsibility for controlling traffic during special events (i.e., The Lake Placid Olympics--References E-3 through E-7, the Rose Bowl Parade--Reference E-1, and the Unuson Festival-- Reference E-9); and traffic engineers and highway patrolmen responsible for incident response and traffic management on freeways in major metropolitan areas.

Emergency enforcement and control procedures were discussed with planners and police officers with experience in each of these areas, the numbers of public safety personnel needed to accomplish basic control measures were determined; alternatives for reducing the number of professional personnel needed for traffic control were investigated; and priorities for traffic control assignments were recommended.

1.4 REPORT ORGANIZATION

Chapter 2 of this report presents an overview of the traffic control problems likely to be encountered during crisis relocation; discusses the probable location of road bottlenecks; outlines such key issues as road capacity, routing, and scheduling; and reviews the traffic control implications of several crisis relocation plans. In addition, statistics describing the nationwide availability of public safety officers are summarized.

Chapter 3 discusses the detailed advantages and disadvantages of a variety of traffic control measures that might be employed under crisis relocation conditions, while Chapter 4 addresses the problems of estimating staffing requirements for each of the promising measures identified in Chapter 3. A final section of Chapter 4 lists unanswered questions and proposes topics for future research efforts.

A separable Appendix (Appendix A) entitled "Crisis Relocation Guidelines for Public Safety Agencies" summarizes emergency traffic control measures, lists the responsibilities of public safety agencies, and provides staffing guidance for public safety personnel charged with traffic control duties under crisis relocation conditions. Additional appendices include a brief discussion of incident-response models (Appendix B) and a reference list (Appendix C).

2. PROBLEM OVERVIEW

This chapter presents an overview of the traffic control problems likely to be encountered during crisis relocation. The likely location of bottlenecks is discussed, such key issues as road capacity, routing, and scheduling are outlined, the traffic implications of several crisis relocation plans are reviewed; and statistics describing the availability of public safety offices are summarized.

2.1 BOTTLENECK LOCATION

The capacity of most regional road networks will be severely taxed by crisis relocation. Severe points of congestion may develop, limiting the flow of vehicles out of the risk area. It is important to anticipate the locations at which these congestion bottlenecks are likely to occur.

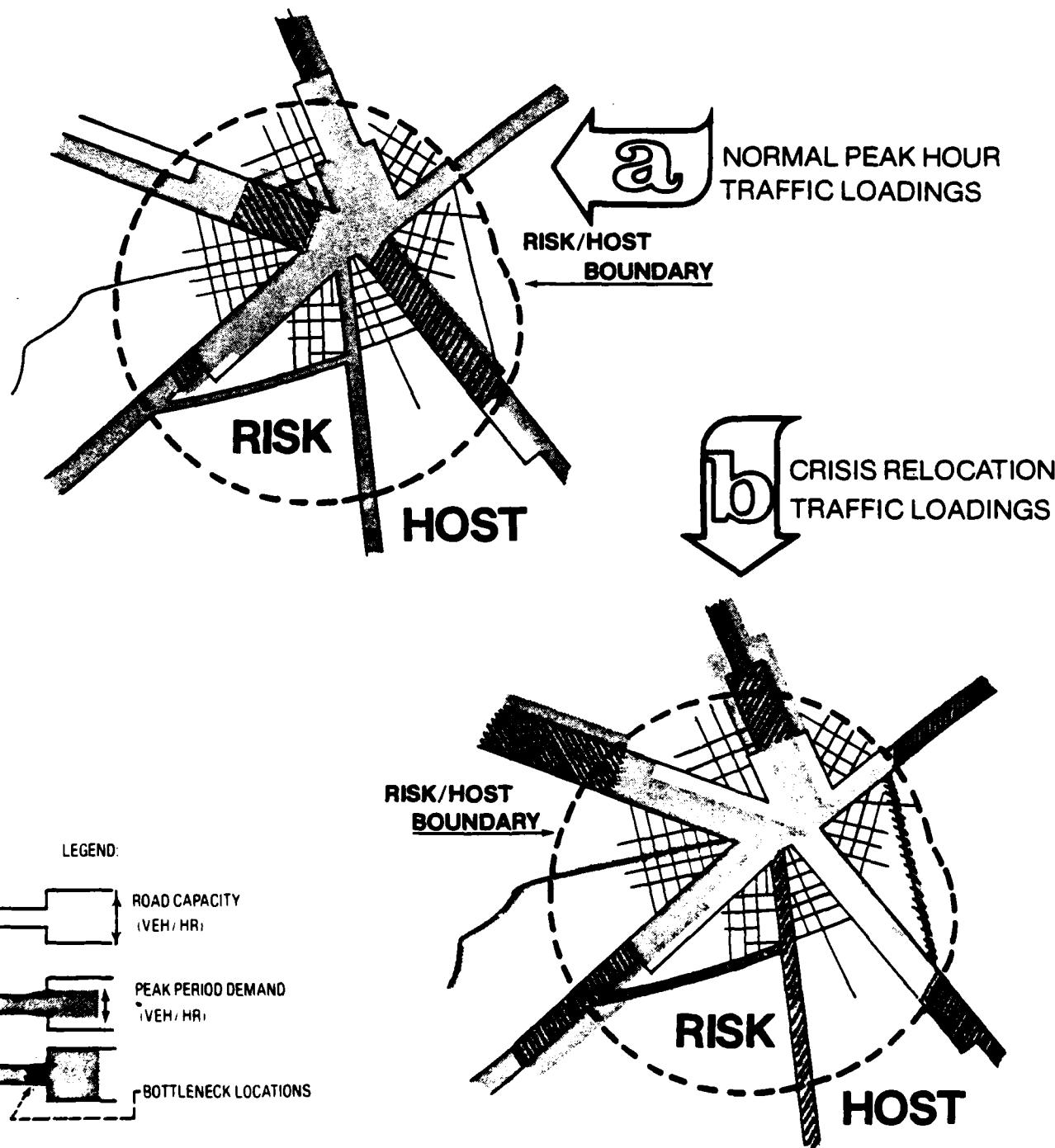
A few officials have in the past tended to minimize the potential impacts of congestion on crisis relocation, arguing that, "We evacuate our major cities every evening rush hour with relatively few problems." While this observation is true, and while there is much to be learned from rush-hour traffic control techniques, the analogy between crisis relocation and the evening rush hour will not stand up under close inspection. The road networks of our major cities have been shaped and sized to accommodate the evening rush hour, and commuters have a certain degree of flexibility in fitting their travel within these networks. These road networks were not built with evacuation in mind. Exhibit 2.1 illustrates this distinction graphically.

Exhibit 2.1(a) charts the typical daily travel patterns within a major city. Morning and evening travel patterns converge on the central business district and other industrial areas, and the road networks are at their most capacious in the vicinity of these major activity centers. Exhibit 2.1(b), on the other hand, sketches the typical flow of traffic under crisis relocation conditions. While the road networks near the center of our major cities can be expected to accommodate these traffic demands, road networks on the outskirts of these cities are likely to be severely strained. Bottlenecks can be expected to develop on narrow rural roads and at freeway constrictions outside the city limits. If an initial rush to evacuate a city causes severe congestion to build up behind these bottlenecks, the success of the entire relocation plan will be threatened.

In their analysis of the New York Metropolitan Area (Reference A-8), Henderson and Strope suggest that planners view the road and highway network as being made up of three elements:

EXHIBIT 2.1

COMPARISON OF NORMAL AND CRISIS RELOCATION TRAFFIC LOADINGS



1. A feeder element composed of streets and minor roads in the risk area.
2. The line-haul network, which includes those roads carrying the heavy traffic flows between risk and host areas; and
3. The distribution network, made up of streets and minor roads in the host area.

The line-haul network is the most critical element in this triumverate. Bottlenecks will occur on the line-haul network somewhere in the juncture between risk and host areas, and it is this network which will require closest supervision and control. The distribution network within the host area will also require close supervision by public safety personnel to make sure that arriving vehicles do not form queues which back up and restrict the capacity of the line-haul network in its critical junctures. The feeder element within the risk area, which has been sized to accommodate large traffic volumes, is likely to require the least supervision of these network elements.

2.2 KEY ISSUES

The success or failure of the relocation strategy will depend to a large extent on the ability of planners and public safety personnel to make maximum use of the capacity of the line-haul network linking risk and host areas. Many potential problems can be solved through careful advance planning, but this planning must address a number of key issues. These include:

- Accurate assessment of highway capacity;
- Routing strategies;
- Departure Scheduling; and
- Movement Control.

These issues must be addressed jointly by planners, traffic engineers, and public safety personnel as part of the planning process. Public safety personnel have a vested interest in this process, since any problems which planners fail to anticipate, address, or solve adequately will plague police officers charged with traffic control on the first day of crisis relocation. The following paragraphs outline the dimensions of each of these key issues.

2.2.1 Highway Capacity

Although the capacities of particular roadways under normal conditions and conditions of peak commuting traffic are well-documented, few empirical guidelines exist for estimating road capacity under the stressful conditions likely to accompany crisis relocation. Data assembled under daily commuting conditions and published in the Highway Capacity Manual (Reference H-8) suggests that the carrying capacity of a limited access freeway can approach 2,000 vehicles per lane per hour. In view of the uncertainties associated with traffic flow under crisis relocation conditions, SYSTAN and other FEMA researchers have insisted that conservative safety factors be applied to Capacity Manual guidelines when planning for crisis relocation (See, for example, Reference A-1 and A-8). Quantitative support for this position was obtained from employees of the California Department of Transportation (CALTRANS) as part of the current study. In monitoring the behavior of weekend drivers unfamiliar with the congested freeways in the vicinity of California speedways and resort areas, CALTRAN'S employees have found that the average freeway capacity is approximately 1,500 vehicles per lane per hour, considerably lower than the Capacity Manual guidance.

A more detailed discussion of roadway capacities may be found in Section 3.5.2. In general, there is little empirical data which can be brought to bear on this issue, which remains one of the most important concerns in crisis relocation planning.

2.2.2 Routing Strategies

Routing strategies attempt to assign particular groups of evacuees to outbound routes in such a way as to minimize the time required to clear the risk area. A successful routing strategy must take into account bottleneck locations, roadway capacities, risk/host assignments, and the use of roadways by adjacent risk areas. To date, most NCP planners have made evacuation route assignments on a rough "trial and error" basis, although several procedures have been developed to assist with the process.¹ All available outbound routes must be used, and contingency plans should be developed in advance to deal with severe tie-ups at bottleneck locations. The monitoring of traffic at these locations and the implementation of contingency plans will typically be the responsibility of public safety agencies.

¹ Formal approaches developed to date include the "20-percent slice" method developed by SRI International for use in the Northeast Corridor (Reference A-8), and the network assignment approaches developed by SYSTAN in preparing transportation guidelines for NCP planners (Reference A-1).

2.2.3 Departure Scheduling

In many risk areas, it is imperative that measures be adopted to persuade evacuees to stagger their departure times, thereby limiting the number of vehicles on the road at any given time and reducing the possibility of severe congestion. Previous evacuation guidance (Reference A-1) separates such measures into two categories:

1. Indirect measures designed to convince the population that a staggering of departure times is in their own best interests (examples include broadcasting traffic information, encouraging off-peak departure times, advising that families take only one auto, and operating support services around the clock); and
2. Direct attempts to schedule departures on the basis of license plates, place of residences, zip codes, access routes, or other identifying characteristics.

Every indirect means of persuasion at the disposal of local authorities should be employed in the interests of minimizing congestion and maximizing roadway efficiency. A key element of relocation planning is the identification of those instances when road capacity is so limited that some direct scheduling of departures is necessary. Careful consideration also needs to be given to the procedures used in direct scheduling. Obviously arbitrary rules which allow one randomly-chosen population group (i.e., those with even-numbered license plates) to precede another, are not likely to be perceived as reasonable or fair in life-threatening circumstances. Therefore, rules of this type are not likely to be widely observed, and provide grist for the mill of those civil-defense critics who claim crisis relocation is "ridiculous." Section 3.2 of this report discusses the advantages and disadvantages of different scheduling procedures in more detail.

2.2.4 Movement Control

Nearly every study of transportation requirements under crisis relocation conditions has suggested that traffic entering main evacuation routes be regulated, or metered, to maximize outbound flow. Traffic control measures that could be needed under crisis relocation conditions might include:

- Establishment of holding areas for vehicles entering the mainline evacuation stream;
- Dynamic redirection of traffic in response to existing flow conditions;
- Perimeter control to deny access to non-essential vehicles attempting to enter the risk area;

- Enforcement of scheduling guidelines;
- Enforcement of minimum occupancy requirements on autos using major evacuation routes;
- Use of "round-robin" convoy techniques to negotiate bottlenecks; and
- Establishment of wrong-way flow on inbound routes to allow all traffic to proceed outbound.

Responsibility for implementing each of these control measures will fall on public safety agencies. As in the case of the scheduling options discussed above, some traffic control measures, such as dynamic redirection and perimeter control, will be needed in every large risk area. Certain other restrictive and potentially controversial measures, such as minimum occupancy requirements and wrong-way flow, should be established only as a last resort when the existing road network is clearly inadequate to handle crisis relocation traffic. In the current study, both traffic engineers and public safety personnel have been consulted in an attempt to identify those conditions under which the more restrictive and risky forms of traffic control are necessary.

2.3 REVIEW OF EXISTING PLANS

In an attempt to assess the current status of traffic planning for crisis relocation, the transportation sections of crisis relocation plans for a range of different risk areas were obtained and reviewed. The plans which were reviewed covered a range of different cities throughout the U.S., and were generally among the more advanced risk area plans developed to date. In reviewing the plans, we were particularly interested in the traffic control measures identified in the planning process, and the prescribed roles for public safety personnel. In addition, an attempt was made to determine the number of available routes outbound from each risk area and assess the likely congestion conditions that might be expected on each route.

Exhibit 2.2 compares the outbound road capacities with the projected evacuation loadings for nine risk areas, ranging in population from 44,000 (Plattsburgh, NY) to nearly two million (The Puget Sound area of Washington). The exhibit lists the average evacuation time for each area, computed by dividing the number of evacuating vehicles by the outbound road capacity.² These times range from under one hour for Plattsburgh to over 50 hours for the Puget Sound area. The exhibit also lists the time required to evacuate along the single most heavily used

² Route capacities were computed by following the procedures suggested in earlier work (Reference A-1) by taking 2/3 the capacity suggested in the Highway Capacity Manual.

RISK AREA:	Colorado Springs, Colorado	Plattsburgh, New York	Sacramento, California	Augusta, Georgia	San Antonio, Texas	Dallas, Texas	Wichita, Kansas	St. Paul, Minnesota	Puget Sound, Washington
POPULATION									
Total Evacuees	131,521	43,650	642,000	142,000	790,000	1,246,100	350,700	1,931,200	1,982,720
Total Vehicles	37,577	11,300	194,084	40,860	171,474	415,635	113,140	643,733	634,905
PERIMETER CAPACITY									
Outbound Flow Capacity ¹ (vehicles/hour)	2,000	14,350	10,002	6,669	15,337	25,338*	6,002*	27,200	12,670
Average Time (hours)	18.79	.79	19.40	6.13	11.18	16.40	18.85	23.67	50.11
CRITICAL ROUTE CAPACITY									
Bottleneck Capacity (vehicles/hour)	667	300	667	667	667	667	667	3,200	667
Assigned Vehicles	14,540	850	24,000	11,236	25,627	20,809	23,000	100,302	74,667
Average Time (hours)	21.80	2.83	35.98	16.85	38.42	31.20	34.48	31.34	111.95
TRAFFIC CONTROL PERSONNEL									
Traffic Control Points	N/A	19	N/A	34	N/A	28†	N/A	N/A	N/A

¹ Assumed Capacity = 2/3 capacity suggested in *Highway Capacity Manual*
 * Some additional capacity available, but not used in plan
 † Perimeter control points

Exhibit 2.2
SUMMARY OF EVACUATION TIMES
COMPUTED FROM EXISTING RELOCATION PLANS

route in the evacuation plan (identified as the critical route in Exhibit 2.2). In the case of most of the risk area plans reviewed, this time is considerably higher than the average evacuation time, suggesting that the plans might be improved by a better balance of outbound flow. (That is, by reassigning some traffic from the most heavily used routes to other exit routes.)

Few of the plans reviewed identified key traffic control points, and only one (Plattsburgh, NY) addressed specific assignments for public safety officers. The Puget Sound plan was the only plan to schedule departure times for different segments of the population, but no provision was added for monitoring or enforcing the suggested departure times.

Two of the cities whose plans were reviewed, Dallas and Wichita, had such an abundance of outbound roads that planners failed to use all available routes in making traffic assignments. On the whole, there were few plans which could not be improved by making use of all outbound routes, balancing the vehicle flow on these routes, devoting more attention to explicit traffic control procedures and developing contingency plans for bypassing bottlenecks.

2.4 POLICE OFFICER STATISTICS

In order to determine whether the officer requirements imposed by various traffic control procedures are feasible, it is necessary to develop estimates of the number of police officers available in cities of different sizes throughout the U.S. According to a recently published FBI document, Crime in the United States 1980 (Reference H-14), the national rate for uniformed law enforcement personnel is 2.1 officers per thousand inhabitants. When civilian law enforcement personnel are included, the rate rises to 2.7. The following table, which breaks down the rate by city size, suggests that the number of law enforcement personnel per thousand inhabitants does not vary too much with the size of a city until the city population exceeds 250,000.

<u>City size</u>		<u>Avg. uniformed and civilian officers per thousand inhabitants</u>
Under -	10,000	2.4
10,000 -	24,999	2.1
25,000 -	49,999	2.1
50,000 -	99,999	2.2
100,000 -	249,999	2.4
Over -	250,000	3.3

Under crisis relocation circumstances, the public safety officers most likely to be called upon to control traffic will be the state highway patrol officers. Accordingly, the number of state police and highway patrol officers are tabulated separately by state in Exhibit 2.3.

Exhibit 2.3
FULL-TIME STATE POLICE AND HIGHWAY PATROL OFFICERS
BY STATE

State ¹	Number of Officers ²	Rate ³ (Officers/1,000 Inhabitants)	State	Number of Officers	Rate (Officers/1,000 Inhabitants)
Alabama	679	.18	Nebraska	385	.15
Alaska	274	.69	Nevada	180	.23
Arizona	879	.32	New Hampshire	222	.24
Arkansas	504	.22	New Jersey	2094	.29
California	5033	.21	New Mexico	339	.26
Colorado	535	.19	New York	3457	.20
Connecticut	874	.28	North Carolina	1137	.19
Delaware	435	.73	North Dakota	97	.15
Florida	1163	.12	Ohio	1150	.11
Georgia ⁴	1009	.19	Oklahoma	624	.21
Idaho	162	.17	Oregon	908	.35
Illinois	1466	.13	Pennsylvania	3672	.31
Indiana	1133	.21	Rhode Island	165	.17
Iowa	557	.19	South Carolina	765	.25
Kansas	404	.17	South Dakota	138	.20
Kentucky	1260	.35	Tennessee	631	.14
Louisiana	824	.20	Texas	2493	.18
Maine	294	.26	Utah	420	.29
Maryland	1559	.37	Vermont	255	.50
Massachusetts	966	.17	Virginia	1289	.24
Michigan	2130	.23	Washington	823	.20
Minnesota	501	.12	West Virginia	565	.29
Mississippi ⁴	575	.23	Wisconsin	438	.09
Missouri	844	.17	Wyoming	157	.34
Montana	199	.25			
TOTAL NUMBER OF OFFICERS			= 46,663		
NATIONAL RATE (OFFICERS/1,000 INHABITANTS)			= .21		

¹Data not available for District of Columbia and Hawaii.

²Source: Crime in the United States, 1980, U.S. Dept of Justice.

³Population figures based on Preliminary Reports of 1980 Census.

⁴Estimated value.

Nationally there are 46,663³ state police and highway patrol officers, which account for about 10% of the total uniformed law enforcement force. The size of state police and highway patrol forces varies widely, ranging from under a hundred to over five thousand officers. California, the most populous state, leads with 5,033 officers, followed by Pennsylvania (3,672 officers) and New York (3,457 officers). North Dakota, on the other hand, has only 97 officers. Since the size of the state law-enforcement force is largely dependent on its population and size, the number of officers per thousand inhabitants is also calculated. The tabulated results indicate that there are wide variations in officer rates among states, ranging from .09 officers/1,000 inhabitants in Wisconsin to .73 officers/1,000 inhabitants in Delaware. The overall national rate for state police and highway patrol officers is .21 officers/1,000 inhabitants.

³ Excluding the District of Columbia and Hawaii

3. CONTROL MEASURES

This chapter discusses the advantages and disadvantages of a variety of traffic control measures that might be employed under crisis relocation conditions. The potential utility of alternative control measures are analyzed from the standpoint of planners, traffic engineers, public safety officers, and other professionals having direct experience with emergency evacuations and traffic control for major entertainment events. The following traffic control topics are discussed:

- Routing Strategies
- Departure Scheduling
- Entry Control
- Perimeter Control
- Network Capacity
- Flow Maintenance

Each discussion includes a one-page summary listing those control measures which should always be employed during crisis relocation, those measures which should be used sparingly, and those measures which should be avoided.

3.1 ROUTING STRATEGIES

Routing strategies are formulated in the planning phase of crisis relocation, when particular groups of evacuees are assigned to specific outbound routes. Successful routing strategies should attempt to minimize the time required to clear the risk areas, and must reflect bottleneck locations, roadway capacities, risk/host assignments, and the use of roadways by adjacent risk areas. Exhibit 3.1 segregates a number of potential activities to be considered in formulating routing strategies into three categories:

1. CONVENTIONAL MEASURES which should always be employed in planning and implementing route assignments;
2. CONTINGENT MEASURES which should be considered only if conventional measures prove inadequate; and

Exhibit 3.1

ROUTINE GUIDANCE

1. CONVENTIONAL MEASURES

ALWAYS

- Use all available outbound roads
- Inspect all evacuation routes
 - during planning
 - prior to crisis relocation
- Balance flows to minimize clearance time
- Provide clear instructions
- Develop contingency plans to bypass potential bottlenecks

2. CONTINGENT MEASURES

If conventional measures prove inadequate, CONSIDER

- Revising host/risk assignments
- Redefining risk areas

3. CONTRAPRODUCTIVE MEASURES

AVOID

- Rigorous enforcement of individual route assignments
- Forcing individuals with personal host-area destinations into conformance with public plans

3. CONTRAPRODUCTIVE MEASURES which should be avoided at all costs.

3.1.1 Conventional Measures

Activities which should be undertaken in every crisis relocation planning effort are summarized in Exhibit 3.1 and listed below.

- Use all available outbound routes. Although the admonition to use all available outbound routes seems obvious, it is not always followed, either in planning or in practice. Several of the risk area transportation plans reviewed in the course of this study failed to make use of all available outbound highway capacity (see Section 2.3). Moreover, the highway patrol officer responsible for overseeing the evacuation of the Corpus Christi area in the face of Hurricane Allen in August, 1980 reports that evacuating vehicles concentrated on two primary exit freeways, causing severe congestion and leaving alternate secondary routes under-utilized.
- Inspect all evacuation routes. All evacuation routes should be visually inspected by planners, traffic engineers, and public safety personnel in the course of the planning process and immediately before any evacuation order is issued. The planning inspection will help to document likely bottlenecks and identify potential options for expanding roadway capacity (perhaps through the use of shoulders or contra-flow segments--see Section 3.5). Inspection just prior to the evacuation will identify instances in which current construction activity is limiting route capacity, or recent construction has expanded capacity.
- Balance outbound flows to minimize clearance times. Evacuation times depend on route capacities, the total number of vehicles assigned to each outbound route, and the rate at which people attempt to leave the risk area. Many combinations of routes and ratings need to be considered in order to find the assignment which minimizes congestion and total evacuation time while filling available host-area space. Earlier guidelines (Reference A-1) document a planning algorithm which satisfies these criteria. The algorithm requires that the risk area be divided into population zones which are easily identified and understood by the evacuees. Census tracts appear to provide the most promising basis for accomplishing this division. People in these risk-area population zones are assigned to routes in order to minimize congestion, subject to the availability of accommodations in the host areas served by the routes.

This assignment process may also be accomplished by trial and error. However, trial-and-error solutions typically leave the planners with a few heavily loaded routes which will require long periods of time to clear. This phenomenon was in evidence in several of the evacuation plans compared earlier in Exhibit 2.2. In

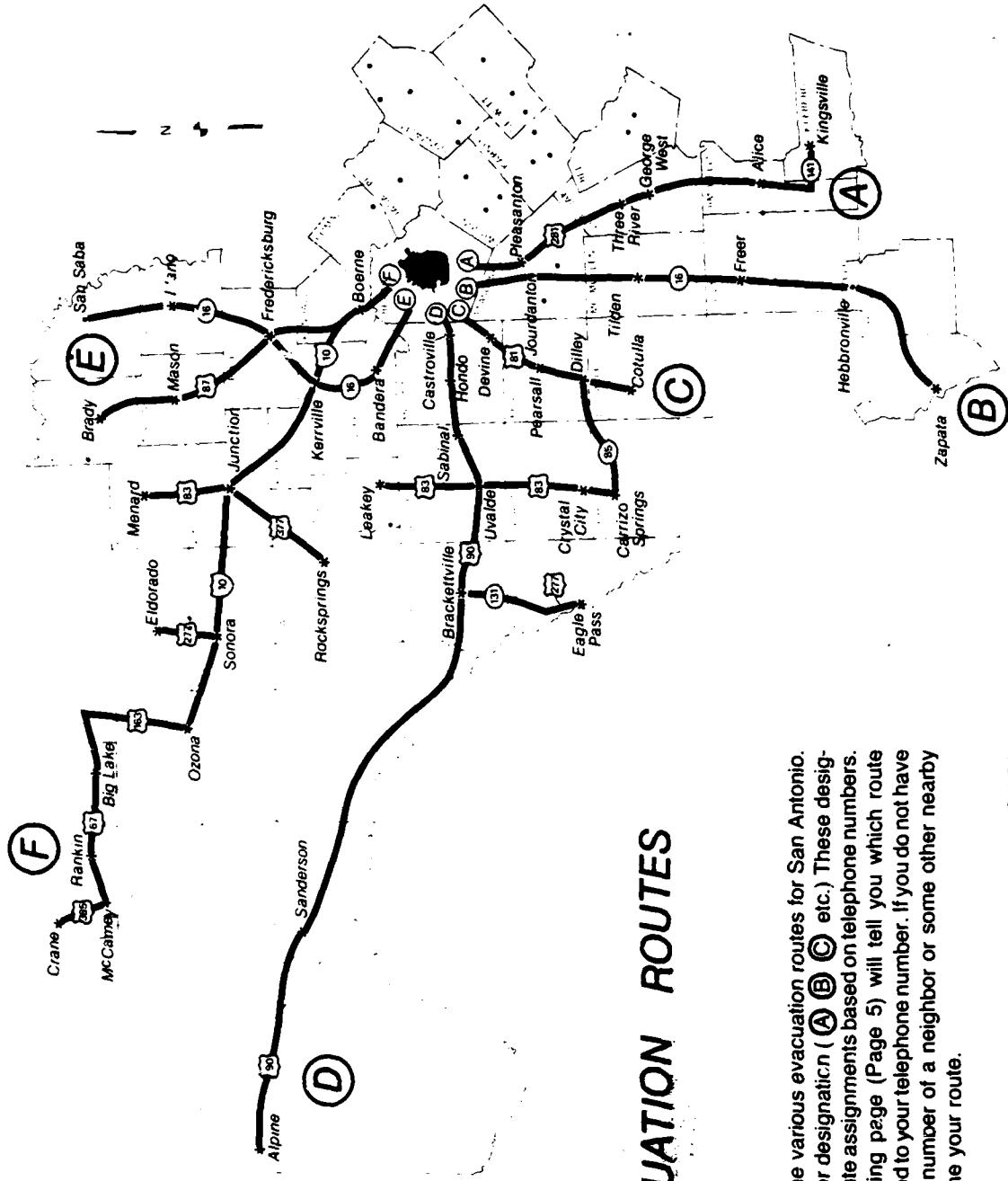
several of these plans, the time needed to evacuate the most heavily used evacuation route was considerably longer than the average evacuation time. This imbalance suggests that the plans might be improved by reassigning traffic from the most heavily used highways to other exit routes.

- Provide clear instructions. Probably the most important element of routing strategy is the development of simple, clear instructions for the public. Exhibit 3.2 shows sample instructions from the San Antonio evacuation plan. In addition to route plans, the agencies responsible for movement control should plan to broadcast continual advisory messages on such current movement information as road conditions, freeway ramp closures, alternate route suggestions, and host-area capacities. This information should reduce anxieties, help evacuees to make maximum use of road capacities, and minimize the need for personal interaction with public safety personnel along the evacuation routes.
- Develop contingency plans. Contingency plans should be developed in advance for dealing with severe tie-ups or lane blockages at bottleneck locations and other key points along evacuation routes. Some jurisdictions develop alternate routings around potential constrictions as a part of incident management and accident response activities. Exhibit 3.3 shows one such routing plan, developed by CALTRANS' Los Angeles Division.

3.1.2 Contingent Measures

In the event that no amount of analysis and route assignment leaves planners convinced that the local transportation network can support the relocation of the risk area residents, local plans should be submitted for review at the regional level. If regional officials concur with the local judgment, certain options remain available. A few of these are discussed below.

- Revise host/risk assignments. The road network available for the use of a single risk area under crisis relocation conditions is greatly affected by the regional assignment of host areas to the various risk areas within the region. It is possible that a reassignment of risk and host areas may increase the potential road capacity of one risk area without damaging the ability of other risk areas to relocate in a timely fashion.
- Redefine risk areas. Should a reassignment of risk and host areas fail to create the desired road capacity, at least one additional option can be explored. Current plans call for the evacuation of all urban areas with populations in excess of 50,000. This planning guidance results in the evacuation of many smaller cities which may not be critical military targets. It is possible that the overall evacuation plan of a region might be improved by



EVACUATION ROUTES

This map shows all the various evacuation routes for San Antonio. Each route has a letter designation (A, B, C, etc.) These designations refer to the route assignments based on telephone numbers. The table on the facing page (Page 5) will tell you which route designation is assigned to your telephone number. If you do not have a telephone, use the number of a neighbor or some other nearby telephone to determine your route.

The table also identifies the highway you will take (e.g. US 281 south) and the assigned reception county and community. Your route is further identified on the simplified route maps given on Pages 6 and 7.

Exhibit 3.2
SAMPLE CRISIS RELOCATION ROUTE MAP

* UN-NUMBERED ROUTE
SET TABLE 1

Source: Reference B-7

	SAMPLE CONTINGENCY-ROUTE PLAN																																																																												
	<p>STAGES OF IMPLEMENTATION</p> <table border="1"> <thead> <tr> <th rowspan="2">ESTIMATED DURATION</th> <th colspan="4">NO. OF LANES CLOSED</th> </tr> <tr> <th>1</th> <th>2</th> <th>3</th> <th>4</th> </tr> </thead> <tbody> <tr> <td>1 HOUR</td> <td>-</td> <td>-</td> <td>1</td> <td>IV</td> </tr> <tr> <td>2 HOURS</td> <td>-</td> <td>1</td> <td>II</td> <td>IV</td> </tr> <tr> <td>2+ HOURS</td> <td>II</td> <td>II</td> <td>II</td> <td>IV</td> </tr> <tr> <td>ESTIMATED DURATION</td> <td>-</td> <td>2</td> <td>3</td> <td>4</td> </tr> <tr> <td>1 HOUR</td> <td>-</td> <td>II</td> <td>III</td> <td>IV</td> </tr> <tr> <td>2 HOURS</td> <td>II</td> <td>II</td> <td>II</td> <td>IV</td> </tr> <tr> <td>2+ HOURS</td> <td>II</td> <td>II</td> <td>II</td> <td>IV</td> </tr> <tr> <td>ESTIMATED DURATION</td> <td>-</td> <td>2</td> <td>3</td> <td>4</td> </tr> <tr> <td>1 HOUR</td> <td>-</td> <td>II</td> <td>III</td> <td>IV</td> </tr> <tr> <td>2 HOURS</td> <td>-</td> <td>II</td> <td>III</td> <td>IV</td> </tr> <tr> <td>2+ HOURS</td> <td>II</td> <td>II</td> <td>III</td> <td>IV</td> </tr> </tbody> </table> <p>PERSONS TO NOTIFY</p> <table border="1"> <thead> <tr> <th>AGENCY</th> <th>TEL. NO.</th> </tr> </thead> <tbody> <tr> <td>CALIFORNIA HIGHWAY PATR</td> <td>213-488-2438</td> </tr> <tr> <td>DEPT OF TRANS. MAINT. COMM</td> <td>213-620-2220</td> </tr> <tr> <td>LOS ANGELES TRAFFIC DEPT</td> <td>213-481-3121</td> </tr> <tr> <td>LOS ANGELES POLICE DEPT</td> <td>213-481-4493</td> </tr> <tr> <td>LOS ANGELES FIRE DEPT</td> <td></td> </tr> </tbody> </table> <p>LEGEND</p> <ul style="list-style-type: none"> — LIMITS OF CLOSURE — PRIMARY ALTERNATE ROUTE ••••• SECONDARY ALTERNATE ROUTE ⊕ SIGNALIZED INTERSECTION ○ STOP SIGN INTERSECTION ◆ SIGNING □ CALIFORNIA HIGHWAY PATRON ▲ LOS ANGELES POLICE DEPT ▼ FIRE STATION 	ESTIMATED DURATION	NO. OF LANES CLOSED				1	2	3	4	1 HOUR	-	-	1	IV	2 HOURS	-	1	II	IV	2+ HOURS	II	II	II	IV	ESTIMATED DURATION	-	2	3	4	1 HOUR	-	II	III	IV	2 HOURS	II	II	II	IV	2+ HOURS	II	II	II	IV	ESTIMATED DURATION	-	2	3	4	1 HOUR	-	II	III	IV	2 HOURS	-	II	III	IV	2+ HOURS	II	II	III	IV	AGENCY	TEL. NO.	CALIFORNIA HIGHWAY PATR	213-488-2438	DEPT OF TRANS. MAINT. COMM	213-620-2220	LOS ANGELES TRAFFIC DEPT	213-481-3121	LOS ANGELES POLICE DEPT	213-481-4493	LOS ANGELES FIRE DEPT	
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<p>EXHIBIT 3.3</p>	<p>ALTERNATE ROUTES</p>																																																																												

I FIELD CHECK ALTERNATE ROUTES
 II ALTERNATE ROUTE TRAFFIC ADVISORIES
 III OFFICER 1 SIGN DEPLOYMENT (MANDATORY DIVISION)
 IV EMPLOY ALTERNATE ROUTE (MANDATORY DIVISION)
 V CLOSE APPROX. CONNECTORS
 VI BARBECUE ON-RAMP CONNECTOR CLOSURES
 NOTE: ROMAN NUMBERS ARE STAGES OF IMPLEMENTATION
 UP TO AND INCLUDING THE STAGE SHOWN

115 NO MEDIUM SHOULDER ON FOR TRAFFIC
 OUTLINE " " "
 (MAJOR PORTION OF CLOSURE AREA, FIELD
 CHECK AT INACCESSIBLE AREA)

allowing residents of smaller cities of marginal military interest to remain in place. The population density of cities in the 50,000 to 100,000 category should not make them particularly attractive targets. In any case, greater population densities will be found following evacuation in host areas surrounding the nation's larger cities. By allowing citizens of smaller cities to remain in place, planners will have greater flexibility in making host area assignments; disruptions caused by crisis relocation will be somewhat limited; the warehouses and fuel terminals and critical industries of unevacuated cities will find it easier to support both the resident population and other relocated populations; and the effective capacity of the regional road network will be increased. Of course, any decisions to alter risk area designations should be made at the national level, where the military consequences of such a decision can be weighed.

Risk areas may also be redefined by shaving the fringes of potential target areas to allow residents exposed to blast overpressures slightly higher than the current threshold of 2 psi to remain in place or by planning to evacuate only blast-threatened regions, rather than regions threatened by either blast or fallout. Such actions will reduce roadway congestion, but they are extraordinary measures which should be adopted only in instances in which the existing road network is clearly inadequate to support crisis relocation.

The potential need to assign different levels of risk to different target areas, or to different geographic sections of a single target area, suggests that FEMA might profitably study the feasibility of redefining risk areas with such distinctions in mind.

3.1.3 Contraproductive Measures

Crisis relocation guidance recognizes that a substantial percentage of the risk population will have a specific location to which they would prefer to relocate during an evacuation. Hubenette (Reference B-1) estimates that this percentage could be as high as 50 or 60 percent of the population. It is also anticipated that 10 to 20 percent of the population might evacuate spontaneously in advance of any official order from the President. As Hubenette points out in Reference B-1:

"These assumptions have a substantial impact on the type and degree of control implemented in support of the movement plan. To the maximum extent possible, the evacuees that have their own personal destination for relocation should be accommodated. Evacuees that go to second homes, friends' and relatives' homes, etc., are less of a burden on the reception areas and particularly on the scarce housing resources in the host areas.

Therefore, the movement control operations should focus on assisting and expediting the movement to the extent possible and employ restrictions only where/when necessary to protect the individual or preserve the integrity of the overall movement plan."

Any attempt to restrict entry to evacuation highways on the basis of preassigned destinations for individual vehicles should be avoided. The process of interrogation will consume manpower that is better used elsewhere, create additional traffic bottlenecks, and serve only to thwart the plans of evacuees with personal destinations, thereby creating a greater burden for public reception areas and host-area housing resources.

3.1.4 The Role of Public Safety Personnel

Public safety personnel have an important supporting role in the development of routing strategies. They should

- Assist in the development of route assignments;
- Participate in planning exercises;
- Inspect evacuation routes during the planning stages and prior to implementations;
- Review contingency plans and be prepared to implement them; and
- Be prepared to provide route instructions and directions to evacuees, as necessary.

Public information handouts and broadcasts should be designed to convey clear, unambiguous messages to evacuees, so that public safety officers need spend a minimal amount of time interpreting instructions for individual motorists. This should free the officers for the all-important task of keeping traffic moving through critical bottlenecks.

3.2 SCHEDULING DEPARTURES

If the perceived danger to a city is real enough to warrant evacuation, then it is real enough to cause people to want to leave as soon as possible. No matter what movement controls are imposed to force a smooth, orderly evacuation, then, it is likely that the initial hours following the announcement of relocation will see a mass exodus in excess of any planning factors reflecting an assumption that departures will be spread uniformly over a two- or three-day period. Moreover, even after the initial rush has subsided, certain hours of the day will

prove more desirable than others for travel, and these hours will further distort assumptions of uniform flow. If an initial rush to the exit routes causes protracted traffic tie-ups, the success of the entire relocation plan may be threatened. Some families may be discouraged from attempting to leave, while others will attempt to use any clear road leading out of the risk area, even if it doesn't lead to an appropriate destination. Extreme tie-ups may lead to panic, abandoned vehicles and the total disruption of the relocation process.

3.2.1 Historical Insights

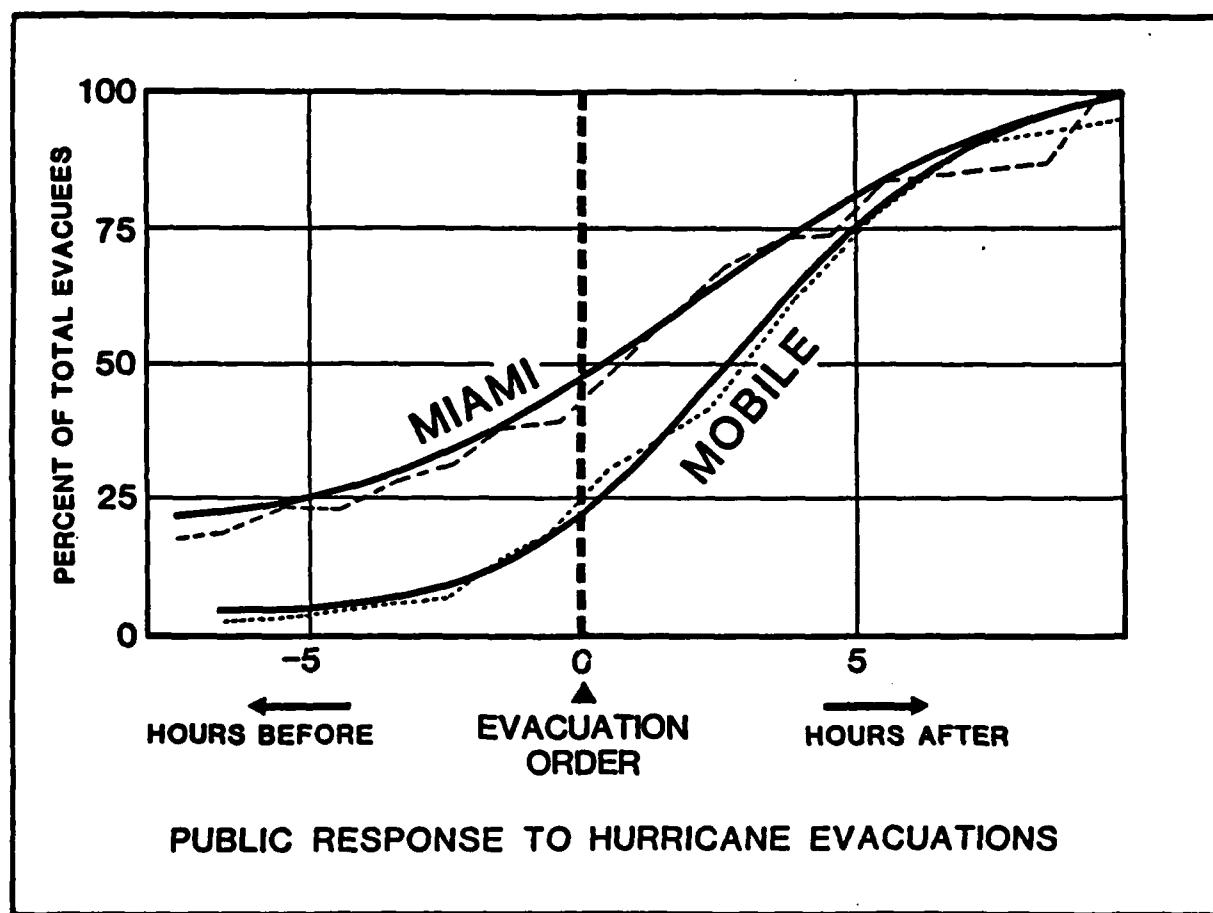
Hurricane Evacuations. Historical evidence of people's behavior in the face of evacuation orders suggests that it will be necessary to attempt to schedule departures in most major cities. Some staggering of departure times will occur naturally. Records of public response to a slowly developing crisis, such as a hurricane, suggest that evacuation actions will be spread over a period of many hours (Reference G-1). Exhibit 3.4 charts evacuation data from two recent hurricanes, Hurricane David in Miami on September 2, 1979, and Hurricane Frederick in Mobile on September 12, 1979. Crosby and Powers (Reference G-1), although cautioning that the relative scarcity of data makes it impossible to draw firm conclusions, found that in each of these cases the response to the emergency closely approximated a normal distribution curve. Even if responses to a crisis relocation order were to spread out over time to resemble the normal distribution shown in Exhibit 3.4, however, most U.S. cities could expect to experience severe traffic jams during crisis relocation. Exhibit 3.4 shows that the hurricane-threatened sections of both Miami and Mobile were cleared of evacuees within ten hours of the official evacuation order. The survey of existing evacuation plans documented in Section 2.3, however, suggests that there are few U.S. cities with sufficient outbound road capacity to clear all evacuees within a ten-hour period. The average evacuation times projected for nine risk areas (and reported in Exhibit 2.2) are repeated below, ranked in ascending order.

<u>Risk Area</u>	<u>Average Clearance Time (hours)</u>
1. Plattsburgh, NY	0.79
2. Augusta, GA	6.13
3. San Antonio, TX	11.18
4. Dallas, TX	16.40
5. Colorado Springs, CO	18.79
6. Wichita, KS	18.85
7. Sacramento, CA	19.40
8. St. Paul, MN	23.67
9. Puget Sound, WA	50.11

Of the nine cities studied, only two--Plattsburgh, NY and Augusta, GA--could be cleared of evacuees within ten hours. Severe congestion could be expected in the remaining cities if evacuees' departures follow

Exhibit 3.4
PUBLIC RESPONSE TO HURRICANE EVACUATIONS

(TIME REQUIRED FOR EVACUEES TO CLEAR RISK AREA)



Source: Reference G-1

the patterns recorded in Miami and Mobile in response to hurricane warnings.

The Mississauga Experience. The evacuation of 217,000 residents of the Toronto suburb of Mississauga within 24 hours of the derailment of a chlorine tanker on Saturday, November 10, 1979 provides additional insights into the behavior of private citizens faced with emergency evacuation orders. As the largest such operation in Canadian history, the Mississauga evacuation has been extensively documented (References D-1 through D-3 and D-5 through D-7) and is often justly cited as an example of exemplary police work under emergency conditions.

In an interview, the police officer responsible for traffic control during the Mississauga evacuation stated that one of the most important elements contributing to the success of the evacuation was the fact that it was approached in stages, beginning with a small one-half square mile sector near the derailment, and fanning out over time as the wind shifted and the extent of the threat became better understood. This staging process kept the evacuation routes from being overloaded and made perimeter control easier. There seems little doubt that the Mississauga evacuation would not have been successful if the police had attempted to evacuate all sectors at once. Mississauga residents responded rapidly to the evacuation orders for their sectors when they were given. Post-incident interviews revealed that 80% of all families left their homes within an hour of the time their sector was declared an evacuation zone (Reference D-3).

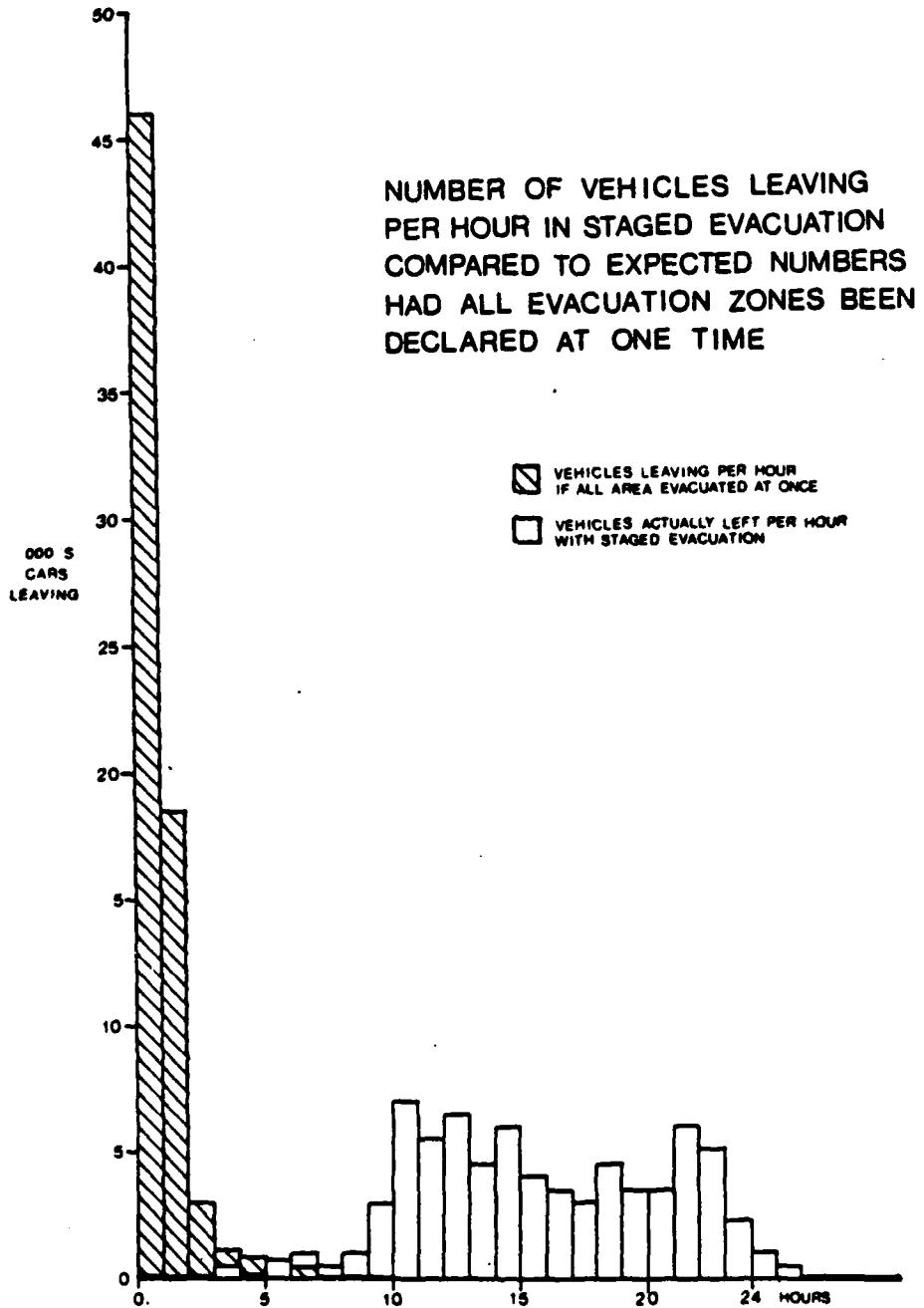
Exhibit 3.5 contrasts the actual flow of vehicles out of Mississauga with the flow which would have occurred if an attempt had been made to evacuate all sectors of the threatened area at once. The staging of the evacuation effectively spread the peak vehicle flows over the better part of a day, limiting the maximum flow to 9,000 vehicles per hour and avoiding the huge traffic jams which would have occurred without staggered departures.

The success of the staging process in Mississauga suggests that departures might be similarly scheduled under crisis relocation conditions in regions where road capacity is limited. By beginning with the densest population areas (or the areas nearest counterforce targets) it might be possible to avoid congestion and fatal delays on key evacuation routes.

3.2.2 Past FEMA Guidance

Past FEMA Guidance (References A-1 and A-10) implicitly recognizes that departures will have to be scheduled if crisis relocation is to succeed in most major cities. Past guidance suggests that scheduling can be avoided only in the unlikely condition that 20% of the total number of evacuees assigned to a route over the three-day evacuation period can leave within one hour without exceeding the route's bottleneck capacity. This condition is sufficiently stringent so that

Exhibit 3.5
IMPORTANCE OF STAGGERED DEPARTURES
IN THE MISSISSAUGA EVACUATION



Source: Reference D-3

it is unlikely to be met on all the evacuation routes in any major risk area. That is, most risk areas will have to make an effort to schedule departures and control flows on critical routes.

3.2.3 Promising Scheduling Approaches

A number of measures may be adopted in an attempt to schedule departures and to limit the number of vehicles on the highways at any time. Exhibit 3.6 classifies the most common of these measures as (1) conventional measures, (2) contingent measures, and (3) contraproductive measures. Past evacuation guidance (Reference A-1) further separates these measures into two additional categories.

1. Indirect measures designed to convince the population that a staggering of departure times is in its own best interests, and
2. Direct attempts to schedule departures on the basis of license plates, place of residence, or other identifying characteristics.

Indirect Measures. Every indirect means of persuasion at the disposal of local authorities should be employed in the interests of minimizing congestion and maximizing roadway efficiency. One of the most important means of influencing departure times and travel patterns will be the frequent broadcasting of information regarding traffic conditions on outbound routes. Such reports also serve to advise motorists of traffic tie-ups and alternative route choices. Previous transportation guidance (Reference A-1) suggests that other means of persuading evacuees to smooth their departure times and limit congestion include: (1) encouraging off-peak departure times; (2) advising that families take only one automobile to the host area; and (3) operating support services around the clock to accommodate departures and arrivals at all hours.

Direct Measures. Certain groups of the population are subject to direct scheduling controls. Bus departures may be scheduled to avoid peak travel hours, and the departures of certain organizational relocatees and key workers may be started early or delayed until the later stages of relocation.

The largest group of relocatees in any risk area will be those with automobiles who are unaffiliated with any controlling organization. This group will undoubtedly be motivated to move as quickly as possible, and poses the greatest potential threat to the free flow of relocation traffic. All of the indirect measures discussed above should be incorporated in the relocation plans for large risk areas and employed to encourage this group to spread their departures over the three-day period. In addition, more direct (and possibly draconian) scheduling measures may be needed to keep early traffic peaks from causing unacceptable congestion. A review of existing plans has shown that road

Exhibit 3.6

SCHEDULE GUIDANCE

1. CONVENTIONAL MEASURES

ALWAYS

- Broadcast information on traffic conditions
- Encourage off-peak departure times
- Operate support services around the clock
- Schedule departures of controllable groups
 - autoless residents
 - critical workers

2. CONTINGENT MEASURES

If conventional measures prove inadequate, CONSIDER

- Scheduling departures of different geographic regions at different times.
 - Begin with most densely populated section
 - Work outward toward host areas

3. CONTRAPRODUCTIVE MEASURES

AVOID

- Arbitrary scheduling rules (i.e. even/odd license plates)
- Scheduling departures during relatively short time intervals (i.e. hour-by-hour)
- Scheduling rules requiring individual vehicle inspection

capacity in most risk area is already so limited that the exodus of unattached households with autos is likely to extend well into the second day of relocation under the best of circumstances.

If direct scheduling of departures is found to be necessary, a circumspect approach might emulate the Mississauga experience by identifying that portion of the target area most "at risk" (i.e., the population center or section nearest a military target) and scheduling relocation of this critical area during the first twelve hours of relocation. In subsequent time-periods, the area to be relocated would be gradually expanded to include the entire risk area. This gradual expansion process would also simplify the task of perimeter control. No overt attempt would be made to keep residents outside the most-threatened area from leaving on (or before) the first day of the announced relocation. Nonetheless, this approach has the advantage of being "fairer" than an arbitrary designation based on license plates or telephone prefixes in that it reflects perceived risk.

One of the few existing risk-area plans to address the scheduling of departures is the plan developed for the Puget Sound area of Washington by FEMA Region X and WCA Consultants (Reference B-7). This plan reverses the Mississauga experience by allowing residents on the outskirts of the risk area to leave first. By basing the scheduling plan on geographic regions, however, the Puget Sound plan lends itself to enforcement through the control of entry to evacuation routes in critical regions. A discussion of entry control procedures may be found in Section 3.3

3.2.4 Unpromising Scheduling Approaches

One means of attempting to force the scheduling of auto departures would be to announce that autos with even-numbered license plates would be allowed access to evacuation routes during the first 12 hours of the relocation period (for example), while autos with odd-numbered plates could depart during the second 12 hours. Although this scheme appears to be enforceable, no serious attempt could or would be made to enforce such a rule, since enforcement would require individual vehicle inspection, and entail additional traffic tie-ups. By way of contrast, geographic scheduling rules have the virtue of lending themselves to enforcement through such passive and effective measures as freeway ramp closure. Scheduling rules using such mechanisms as license plates or telephone prefixes also have the severe drawback of being obviously arbitrary. Such arbitrary rules are not likely to be perceived as reasonable or fair in life-threatening circumstances, and consequently, may not be widely observed. Such rules, moreover, provide grist for the mill of the cassandras who claim crisis relocation is "ridiculous" and "impossible."

In the past, planners have been understandably leery of proposing movement plans which required certain population groups to move on schedule within relatively small spans of time. In an earlier study,

Strope (Reference A-11) cautioned against fine-grained, hour-by-hour schedules, noting that,

"Use of many partitions of the traffic load, such as assigning a time to each terminal number in an automobile license plate number, is not recommended, even though this would further smooth out departures. Asking those destined for particular host counties to delay leaving in preference to others is unlikely to be perceived as reasonable and fair."

By restricting freeway entry at limited control points to a narrow range of permissible times, moreover, the planner runs the risk of creating congestion and back-ups at those points, so that some portion of vital freeway capacity beyond the clogged access points will be under-utilized. "In the final analysis," Strope concluded, "emergency public information must reiterate that, if the rules are not followed, unattached households will find themselves in the worst traffic jam they have ever experienced." (Reference A-11)

3.2.5 The Role of Public Safety Personnel

The development of departure schedules will be accomplished by NCP planners, acting with local traffic engineers and city planning representatives. Public safety personnel have a supporting role in this activity, and should be prepared to participate in planning exercises and review the schedules from the standpoint of consistency.

As with route plans, public safety personnel should be sufficiently familiar with relocation schedules to interpret them for confused motorists, and to implement the schedule by establishing entry controls at key intersections and freeway ramps.

3.3 ENTRY CONTROLS

Nearly every study of transportation requirements under crisis relocation conditions suggests that traffic entering the main evacuation routes be regulated, or metered, to maximize outbound flow. Controls may be active or passive, dynamic or static. As explained in an earlier study of transportation under CRP conditions,

"Active controls might be exercised by having policemen direct each vehicle to a specific route and destination on the basis of driver interrogation and vehicle identification. An example of passive control would entail the barricading of a street to limit route choices. Dynamic controls are capable of adjusting to reflect hourly traffic conditions as monitored by helicopter or observers at key intersections. Static

controls are those which remain in place, unchanged, throughout the duration of the relocation period. The establishment of a contra-flow lane for outbound traffic serves as an example of a static control." (Reference A-1)

The ideal control for crisis relocation is passive and static. Passive barricades at freeway ramps and key intersections can support published departure schedules by denying direct access to evacuation routes to specific geographic groups. These barricades may be removed at predetermined times to permit access in conformance with published departure schedules. The changing nature of evacuation conditions may require that many entrances to major evacuation routes be staffed by traffic control officers (i.e., be active and dynamic).

3.3.1 Recommended Measures

Exhibit 3.7 summarizes recommended entry control procedures, and lists a few techniques which are not likely to be effective under emergency conditions. As noted, the most effective and efficient means for regulating entry to evacuation routes is to block key intersections and freeway entrance ramps temporarily with large vehicles such as trucks or trailers. Public safety personnel may remove those barriers in response to changing traffic conditions or published departure schedules. Such barricades need not be manned continuously, although aerial surveillance units should monitor the key control points on a regular basis to ensure that they are not breached. Agencies responsible for planning the barrier controls will have radio-dispatched vehicles that can be sent to the scene if repairs are required. Signs should be erected to point out alternative routes and advertise the time at which the barricades will be removed.

Where continual metering of flow is desired, police officers can be placed at key intersections and on-ramps to make sure that traffic levels do not approach critical densities. Police control will certainly be necessary to direct competing streams of traffic at key intersections.

Some traffic engineers experienced in vehicle control around major sporting events were skeptical of the effectiveness of stationing personnel at freeway on-ramps to control traffic access during emergencies. Effective real-time metering of flow requires an ongoing knowledge of traffic conditions upstream and downstream from the control point, as well as an ability to assimilate and act on this knowledge. Such metering can be accomplished effectively by traffic signals in the relatively predictable conditions accompanying rush hours. Experience in one-of-a-kind events, however, suggests that officers stationed at on-ramps tend to rely exclusively on flow conditions at that ramp in selecting a metering strategy. (If traffic is moving well at their station, officers will allow more cars to enter the roadway.) Since the traffic conditions themselves can serve a similar metering function,

Exhibit 3.7

**ENTRY CONTROL GUIDANCE
= OUTBOUND ROUTES =**

1. CONVENTIONAL MEASURES

ALWAYS

- Identify key traffic control points
- Establish passive barricades using heavy equipment at controlled freeway ramps and intersections where access to outbound routes is to be cut off. Monitor with aerial surveillance.
- Assign traffic control officers to key intersections where streams of outbound traffic merge.

2. CONTINGENT MEASURES

If conventional measures prove inadequate, CONSIDER

- Stationing police officers at barricades
- Using police officers to meter flow onto freeway exit routes.

3. CONTRAPRODUCTIVE MEASURES

AVOID

- Moveable barricades (saw horses or cones)
- Permit systems requiring individual vehicle inspection in outbound traffic streams
- Denying access to individuals with personal host-area destinations which do not conform with public assignments

officers might be better employed in monitoring flow through bottlenecks and responding to congestion-causing incidents.

3.3.2 Contraproductive Measures

- **Movable Barricades.** Traffic engineers and public safety personnel agreed that movable barricades (i.e., saw horses and plastic cones) are useless during today's rush-hour conditions and would certainly not deter traffic under life-threatening conditions. Even today, drivers typically move or ignore such barricades. When CALTRANS needs to protect working crews, they put heavy equipment across the lanes to be closed. They suggest that this approach, at a minimum, would be necessary to control access to roads during crisis relocation.
- **Individual Vehicle Inspection.** Control schemes requiring individual vehicle inspection before granting access to evacuation routes should be avoided. Such schemes are personnel-intensive, put public safety officers in the untenable position of denying life-saving freeway access to some while admitting others, and create additional bottlenecks on the outbound routes. Vehicle inspection points will, however, be required at key points in inbound lanes to control access to the risk area (see **Perimeter Controls** in Section 3.4).

3.3.3 The Role of Public Safety Personnel

Public safety personnel have a primary role in planning, implementing, and maintaining entry controls to outbound routes under crisis relocation conditions. They should

- Participate in the identification of key control intersections and critical freeway ramps;
- Prepare maps on which all controlled entry points are individually numbered, so that supervisors may direct officers to these posts;
- Assist in placing barricades where needed;
- Retain control of keys to any heavy equipment used as barricades;
- Assign traffic control officers to key intersections, manned barricades, and metered freeway ramps; and
- Maintain aerial surveillance of unmanned barricades.

3.4 PERIMETER CONTROLS

Emergency Highway Traffic Regulation (EHTR) posts will have to be established in the inbound lanes leading to the risk area and at other critical points along the highway network. These control points will be needed to seal off the risk area and insure that entry is restricted to authorized vehicles. The posts will be staffed with police officers and auxiliary personnel who will interrogate drivers of vehicles, examine and issue road-use permits, and direct inbound traffic. General guidance for perimeter control may be found in Exhibit 3.8.

3.4.1 Control Post Selection

Ideally, perimeter control posts should be established along all avenues through which the risk area may be entered. The minimum set of posts is likely to correspond to the bottleneck locations identified for outbound traffic. Public safety personnel should review proposed risk-area boundaries from the standpoint of their ability to defend these boundaries against illegal entry. If it is impossible to establish control posts at all possible entry points, points without control posts should be patrolled by officers stationed at nearby posts.

Additional concerns in establishing EHTR posts may be found in the Federal Highway Administration's "Guide for Highway Traffic Regulation in an Emergency" (Reference C-5). This guide warns that,

"...Control posts on routes with sizable traffic streams should be located where plenty of off-the-road parking is available to serve as a holding area. In fact, the post can hardly operate successfully without this. The space may only be a pasture; or, with luck, it may be the parking lot of a big shopping center, industrial plant, drive-in theatre, or athletic field. In addition to space needs, the holding areas will require suitable entrances and exits,..."

The shoulders along the regulated route, whether paved or not, cannot be used as a holding area. Their use of this purpose would seriously endanger moving traffic; they would not have adequate capacity within a reasonable distance; and vehicles stored on them could not satisfactorily be controlled or shifted." (Reference C-5)

Essentially, the operation at the control posts is to allow permit-bearing vehicles to continue into the risk area, issue permits where necessary to essential vehicles and turn away non-essential vehicles. For this reason, the holding area must be of adequate size and located near both the control post and alternative access roads.

Exhibit 3.8

**PERIMETER CONTROL GUIDANCE
= INBOUND ROUTES =**

1. CONVENTIONAL MEASURES

ALWAYS

- Establish control posts on all inbound routes
 - at outskirts of host area (early days of evacuation only)
 - at host-area/risk-area boundary
- Assign officers and auxilliary personnel to control posts
- Lay out holding areas adjacent to control posts

During the first few days of the relocation period, control posts and holding areas should also be established on the outskirts of host areas at locations removed from risk area boundaries (see Exhibit 3.9). These outlying control points should be signed to intercept traffic destined for the risk area and are necessary to avoid overloading outbound traffic streams with rejected vehicles. Vehicles arriving at the outlying control point may be processed in several ways. They may be allowed to:

1. Proceed to the risk area if they already have an official road-use permit;
2. Obtain a permit and then proceed to the risk area;
3. Follow an alternative route around the risk area;
4. Turn around and return to their origin;
5. Proceed to the nearby host area.

If all vehicles destined for the risk area are allowed to proceed to the risk-area boundary before being intercepted, those vehicles which are turned back or asked to proceed to the host area will be forced into the outbound traffic stream, thereby contributing to an already congested situation.

Once the evacuation of the risk area has been completed, the outlying control points may be abandoned and the officers assigned to these posts should be reassigned to control posts along the risk area perimeter. If no attack has occurred within the three-day evacuation period, experience with other emergencies (see, for example, the Mississauga Report, Reference D-3) suggests that some risk-area residents will begin agitating to return to their homes. The reassignment of officers from outlying control points to the risk-area perimeter should help to frustrate illegal reentry.

3.4.2 Entry Permits

An entry permit is a legal form issued to authorize specific travel into the risk area over a designated route at a particular time. The essential elements of such a permit include: date, route number, time of entry, destination, number of vehicles, and issuing office. A sample road use permit appears in Exhibit 3.10. The legal basis, terms of use, distribution mechanics, and other details surrounding the issuance of road-use permits for restricted areas are discussed in detail in the Guide for Highway Traffic Regulation in an Emergency (Reference C-5).

The EHTR Guide dictates that,

"...State organizations responsible for emergency highway traffic regulations will stock master copies of

EXHIBIT 3.9

TYPICAL LOCATION AND LAYOUT OF PERIMETER CONTROL POST

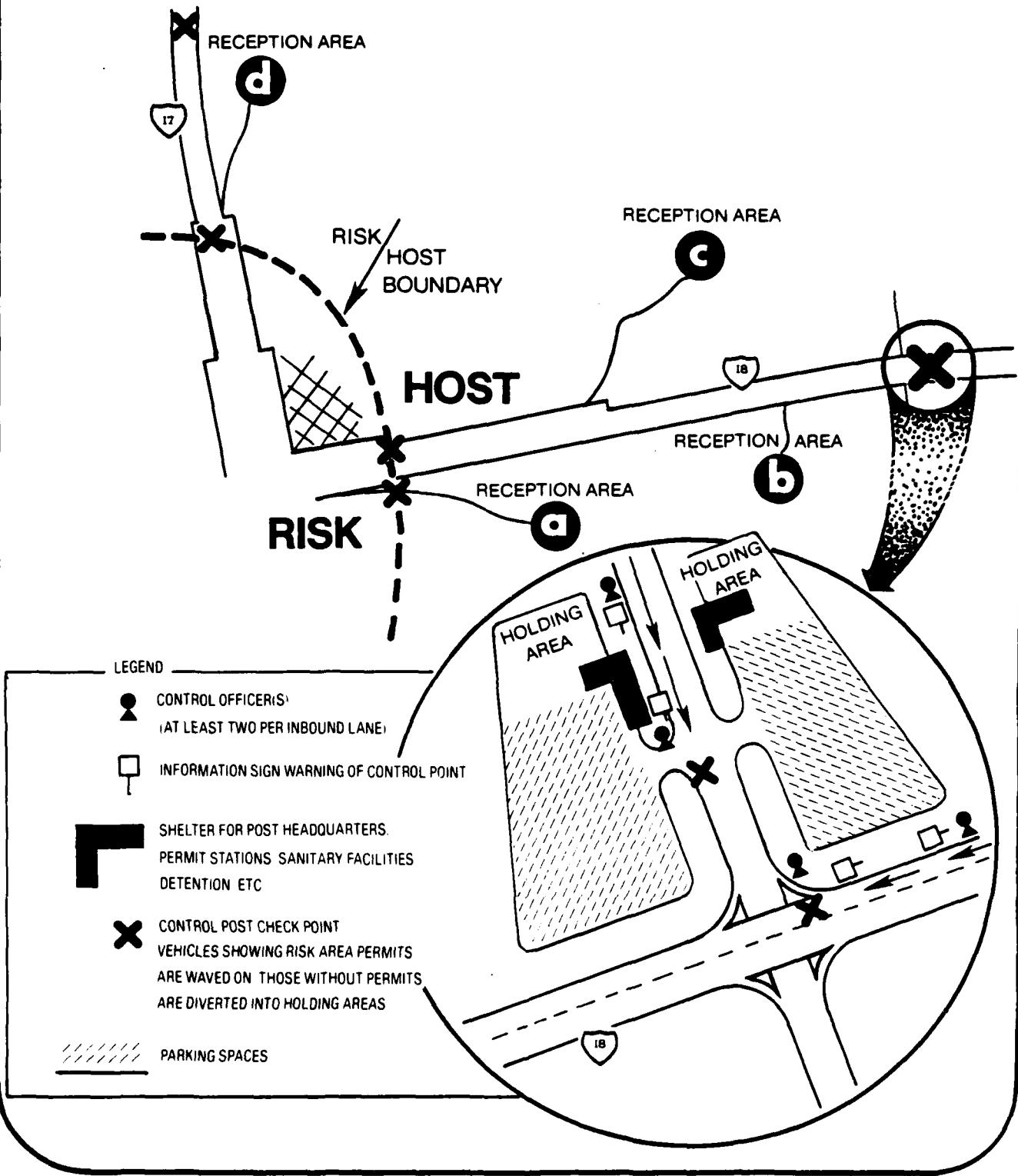


Exhibit 3.10
SAMPLE ROAD-USE PERMIT

No. A 0,000,001		
Trip origin _____ Trip destination _____ Number and type of vehicle _____ Owner _____ Commodity _____ Shipment priority _____ Regulated route number _____ Authorized time of entry _____ (and/or such other items of information as may be appropriate)		
Issuing EHTR Center _____ By _____		
← (Perforated line)		
12 11 10 9 8 7 6 5 4 3 2 1	Number of vehicles authorized Highway Road-use Permit for Regulated route number 22 Issuing EHTR Center By _____	12-1 1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12 12-1 1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12
Time of entry on to regulated route		A.M. P.M.
Valid only on _____		19
ROAD-USE PERMIT TO BE ISSUED		
STATEMENT OF PENALTY FOR MISUSE TO BE PRINTED ON BACK OF FORM!		
This permit is the property of the United States Government. Its counterfeiting, alteration or misuse is a violation of 18 U.S.C., Section 499 (1948). Violators shall be fined not more than \$2,000 or imprisoned not more than five years, or both.		

this permit form available for quick reproduction in the event the need for it arises." (Reference C-5)

It is further expected that commercial vehicle operators with large fleets dedicated to the movement of critical goods, and essential industries with cadres of critical workers will be furnished with pads of permit forms and instructed regarding their purpose and use as during the pre-location planning process. If this advance distribution has not been accomplished, the EHTR Guide goes on,

"...it should be done quickly after the beginning of an emergency. It is evident, of course, that handing out blank permit forms must be done with some discretion and that they should be given only to trustworthy individuals in established and reliable concerns."

To cover the many instances in which critical workers or essential cargo shipments arrive at the risk area without entry permits, permit-issuing stations should be established in the holding area associated with each traffic control points. Similar stations should be scattered throughout host areas.

3.4.3 Potential Problems

Past experience with prioritized entry permits (as during the 1980 Winter Olympics at Lake Placid, References E-3 to E-7) suggests that they work well in conjunction with other control elements but require a sizable staff to administer. Hence it is possible that the early days of relocation will find permit systems in different states of readiness in various states. Officers and volunteers at perimeter control points will have to be granted considerable discretion and latitude in dealing with traffic bound for risk areas at the time of the evacuation order.

One of the most significant problems faced by the Mississauga police was the control of the perimeter surrounding the evacuated area once the evacuation period stretched beyond two days and residents wanted to return home. The Mississauga report cites the following problems with perimeter control:

"The large evacuated area meant that there was a long outer cordon to seal off and maintain. Two problems arose in relation to the perimeter:

- communications between the Control Group and police officers manning road-blocks sometimes broke down, so that the officers were unaware for sometime of decisions that they were supposed to implement;
- there was inconsistency in decisions taken by individual officers about letting people in and keeping others out.

These inconsistencies were soon identified by more persistent members of the public who took advantage of them, to enter the restricted zone....

problem in maintaining perimeter control was that residents had better detailed knowledge of the configuration of streets and gardens than had most police officers. Residents were therefore able to enter the area undetected."

3.4.4 Role of Public Safety Personnel

Public safety personnel have the lead responsibility for securing the risk area, patrolling the perimeter to prevent illegal reentry, and intercepting and interrogating incoming traffic. Effective perimeter control requires that public safety personnel:

- Select control post locations along all avenues of approach to the risk area;
- On major routes, posts should be established both at the outskirts of the risk area and at the host-area/risk-area boundary. All posts should be individually numbered to assist supervisors in planning and implementing control assignments;
- Lay out ample traffic-holding areas in the vicinity of each control post;
- Assign officers and auxiliary personnel to each control post;
- Promulgate guidelines for issuing entry permits;
- Maintain permit-issuing stations at each control post;
- Intercept and interrogate all traffic bound for the risk area; and
- Patrol the perimeter of the risk area to discourage illegal entry.

3.5 CAPACITY EXPANSION

3.5.1 Capacity Measurement

The availability of road capacity is a major concern in crisis relocation planning. Unfortunately, the proper assessment of this critical factor has always been one of the key stumbling blocks in the crisis relocation planning process. Basic transportation planning guidance cautions that:

"The capacity of most regional road networks will be severely taxed by the relocation effort. Bottlenecks are likely to develop on narrow rural roads outside city limits. If an initial rush to evacuate the city causes severe congestion to develop behind these bottlenecks, the success of the entire relocation plan will be threatened. Although many of the potential road capacity problems may be solved through careful advance planning, planners must recognize that rated road capacities are not likely to be attainable for twenty-four hours per day, and that severe peaks in travel patterns may be expected, particularly on the first day of relocation. Assumptions of smooth flow over a twenty-four hour period will result in overly optimistic and potentially disastrous assessments of road network capacities." (Reference A-1)

The speed at which traffic flow is maximized for a particular roadway under normal flow conditions is well understood by traffic engineers. A wealth of empirical evidence has been assembled relating traffic speeds and throughput rates to roadway capacity. Exhibit 3.11 illustrates these relationships in terms of a speed/capacity curve in which traffic speeds are related to the volume/capacity (v/c) ratio of the roadway. Maximum throughput ($v/c = 1$) is attained at traffic speeds of approximately 35 miles per hour. At higher speeds, the spacing between vehicles increases and the throughput rate is reduced. At the lower speeds associated with congested flow conditions, traffic flow drops well below the maximum rate and may break down completely.

Although the capacities of particular roadways under normal conditions and conditions of peak commuting traffic are well-documented, few empirical guidelines exist for estimating road capacity under the stressful conditions likely to accompany crisis relocation. Data assembled under daily commuting conditions and published in the Highway Capacity Manual (Reference H-8) are displayed in Exhibit 3.12. The exhibit shows three classes of roadways: (1) Two-lane undivided roads; (2) Multi-lane rural highways with two or more lanes in each direction; and (3) Limited-access freeway.

In view of the uncertainties associated with traffic flow under crisis relocation conditions, SYSTAN and other FEMA researchers have insisted that conservative safety factors be applied to Capacity Manual guidelines when planning for crisis relocation. Exhibit 3.12 also lists crisis relocation planning factors suggested by two FEMA researchers for each of the three types of roadway described in the Capacity Manual.

Exhibit 3.11
SPEED – VOLUME DIAGRAM

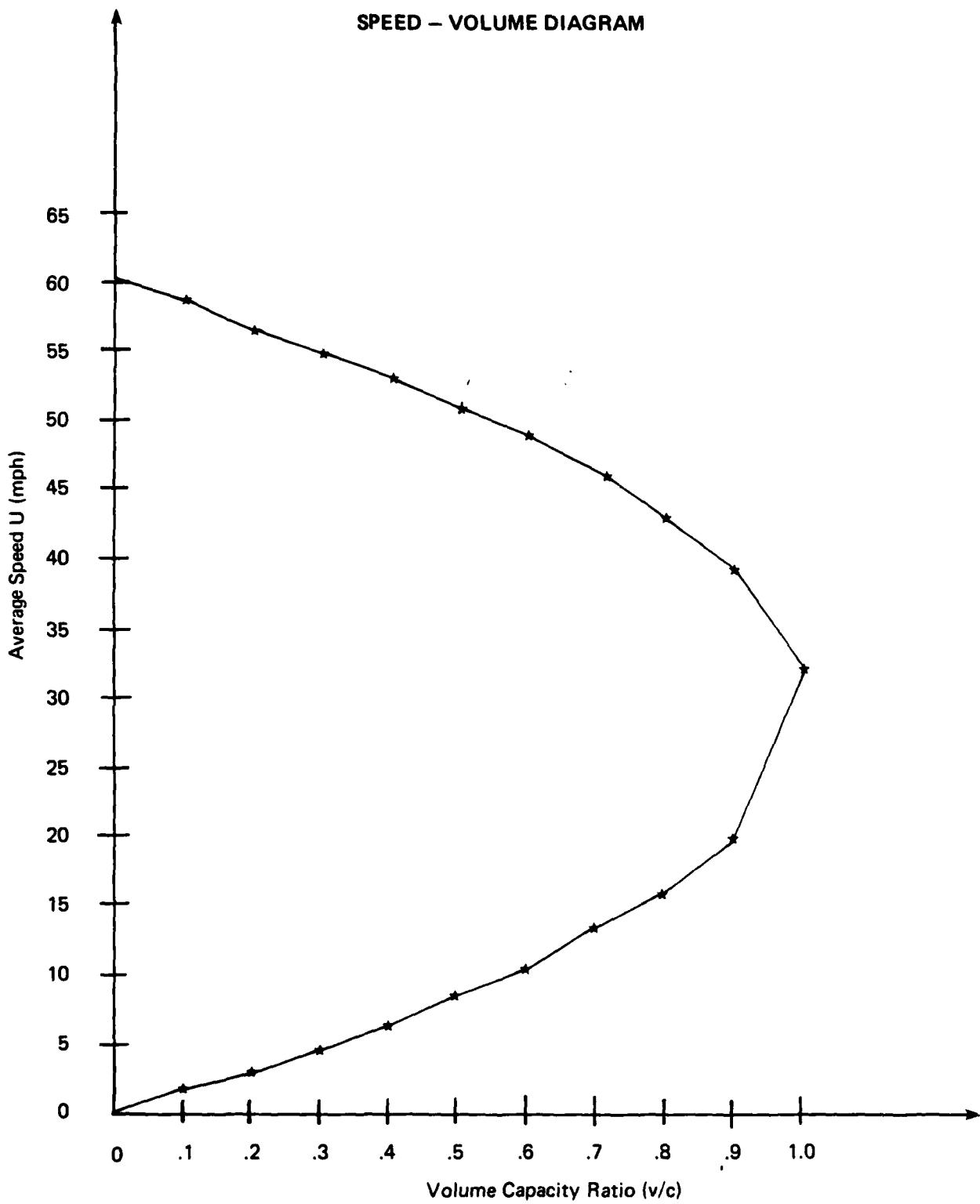


Exhibit 3.12
ROAD CAPACITY PLANNING FACTORS

TYPE OF ROAD	Free Flow Conditions Source: Highway Capacity Manual		Forced Flow Under Ideal Uninterrupted Commute Conditions Source: Highway Capacity Manual		Recommended Crisis Relocation Road Capacity Planning Factors (Vehicles per Lane per Day)	
	MAXIMUM VOLUME (VPH/LANE)	AVERAGE SPEED (m.p.h.)	CAPACITY (VPH/LANE)	SPEED (m.p.h.)	Source: NCP GUIDELINES (Ref. A-1)	Source: NEW YORK STUDY (Ref. A-8)
Two-Lane Undivided Rural Roads with One Lane in Each Direction	400	45	1200	30	32,000	30,000
Multi-Lane Rural Highway with Two or More Lanes in Each Direction	800	50	2000	30	24,000	24,000
Multi-Lane Divided Freeway or Expressway with Limited Access	1200	55	2400	30	16,000	18,000

Relocation planning factors are provided in terms of daily lane capacities¹ and are considerably more conservative than the capacity factors recorded under daily commute conditions. Quantitative support for this conservative position was obtained from employees of the California Department of Transportation (CALTRANS) as part of the current study. In monitoring the behavior of weekend drivers unfamiliar with the congested freeways in the vicinity of Southern California's Ontario Motor Speedway, CALTRANS' employees found that the average freeway capacity under these conditions was approximately 1,500 vehicles per hour, considerably lower than the Capacity Manual guidance for commute traffic.

Additional support for these observations was also obtained from engineers in CALTRANS' Sacramento office, who had compared weekend traffic flows on major freeways with flows on those same freeways during the daily commute period. They found that weekend traffic through highway bottlenecks leading to Northern California resort areas flows at a rate that is consistently 10% to 20% lower than the rate observed at those same bottlenecks during weekday commuting periods. That is, the masses of vehicles traveling largely unfamiliar routes on weekends make less efficient use of California's roads than the cars driven by experienced commuters during their day-to-day trips to and from work. These findings provide quantitative support for the intuitive position that Capacity Manual observations made during peak commuting periods should not be applied uncritically to crisis relocation planning.

Not only are peak-hour highway capacities likely to drop under crisis relocation conditions, but it is extremely unlikely that rated flow rates will be maintained for 24 hours per day. If the number of vehicles traveling through the bottleneck falls below capacity for any length of time, the loss of throughput cannot be made up. On the other hand, if too many vehicles attempt to negotiate a bottleneck, both speed and throughput may suffer. Accidents, stalled vehicles, and anxiety are also likely to reduce effective roadway capacity over a 24-hour period.

The California Highway Patrol estimates that for each minute traffic is blocked completely, ten minutes are required to clear the resulting traffic jam (Reference A-1). While complete blockage is rare for freeways with more than two lanes in each direction, accidents in a single lane can cause disproportionate flow stoppage. For example, if one lane out of three is blocked by an accident (a 33 percent stoppage), the flow rate drops by 50 percent for the entire roadway (Reference A-9). If no lane is blocked, but there is an accident-related activity, a disabled vehicle, or an enforcing officer present on the side of the

¹ The crisis relocation planning factors shown in Exhibit 3.12 were produced by two independent researchers and are in relatively close agreement for each of the three types of roadway under consideration. These factors, however, sometimes reflect markedly different assumptions regarding individual lane capacities and effective operating hours, indicating the uncertainties surrounding the question of highway capacities during extended emergencies.

roadway, flow rates may drop by as much as 25 percent.

In addition to accident-related stoppages, freeway flow can break down completely if entering vehicles cause the capacity of the roadway to be exceeded for significant periods of time. Thus it is unlikely that the reduced flow rates possible under crisis relocation conditions can be attained over a 24-hour period. In the face of the uncertainties associated with traffic flow under relocation conditions, SYSTAN and other FEMA researchers (References A-1 and A-10) have insisted that NCP planners apply conservative safety factors not only to rated highway capacity figures but also to the length of time flow can be maintained during a 24-hour period. The planning factors listed in Exhibit 3.12 have incorporated safety factors, and assume that bottleneck flow will be maintained between 16 and 20 hours per day during an evacuation. Since little empirical data exists, there is no way of knowing whether these factors are too conservative or not conservative enough, and the issue of road capacity estimation remains one of the most important concerns in crisis relocation planning.

3.5.2 Conventional Measures

A number of measures may be adopted in an attempt to expand the capacity of evacuation routes. Exhibit 3.13 lists several of these measures, classifying them as (1) conventional measures to be employed at all times and (2) contingent measures which should be considered only if conventional measures prove inadequate. These measures should be considered in the course of the personal inspection tour undertaken in developing route assignments (see Section 3.1). In order to obtain the greatest value from the capacity expansion measures listed in Exhibit 3.13, they should be concentrated on those capacity bottlenecks which limit traffic flow potential along outbound routes.

- Shoulder Use. Wherever possible, road capacity should be expanded by using the shoulders of freeways and expressways to accommodate an extra lane of traffic. Any use of shoulders must be well considered, well-signed, and must be possible for significant stretches if real gains are to be realized. Otherwise, limited use of shoulders will just shift bottleneck locations and cause severe merging problems when shoulder-users attempt to merge back into the general flow of traffic. CALTRANS' personnel have pointed out that the uninterrupted use of shoulders is not likely to be possible over significant stretches of most freeways, because highway bridges over 120 feet in length typically have no shoulders. (The Federal Highway Administration, which supplied up to 90% of the capital cost of the Interstate system, would not contribute to the funding of shoulders on longer bridges.) In any case, visual inspection of all evacuation routes is essential to determine any capacity limitations and expansion possibilities.
- Emergency Traffic Regulation Signs. Emergency traffic regulation signs are needed in the risk area, along evacuation routes, and in

Exhibit 3.13

CAPACITY EXPANSION GUIDANCE

1. CONVENTIONAL MEASURES

ALWAYS

- Make maximum use of shoulders
- Post adequate signs for traffic control
- Adjust signal timing to favor outbound traffic
- Encourage "first-auto" use

2. CONTINGENT MEASURES

If conventional measures prove inadequate, CONSIDER

- Establishing wrong-way flow on inbound routes
- Adopting vehicle occupancy restrictions on such separate rights-of-way as bus lanes and carpool lanes

host areas. Proper signs are needed on any closed routes or access ramps to inform motorists where the nearest alternate route or access point can be found. Signs should also be provided along evacuation routes to reassure motorists that they are on the right path, direct evacuees to rest areas and traffic control points, and identify exits to host area reception centers. Several specifications for sign design and placement are contained in The Manual on Uniform Traffic Control Devices for Streets and Highways (UTCD) published by the Federal Highway Administration of the U.S. Department of Transportation (Reference). A section of the UTCD Manual titled "Signing for Civil Defense" includes signs for use during a national defense emergency. The EHTR Guide (Reference C-5) cautions that "These signs should be available when needed in an emergency and provision should be made, therefore, for having these signs stockpiled and ready for use should the need arise." In addition to special signs, crisis relocation will place heavy demands on the stockpiles of such standard traffic direction devices as cones, arrows, and other direction markers. Public agencies should make arrangements with local construction industry representatives to use privately held stockpiles of direction makers during the evacuation period.

- Signal Timing. Signals on main evacuation routes should be set to favor outbound traffic, and public safety officers should retain keys to all signal boxes within their jurisdictions. During the evacuation of Texas coastal areas in advance of Hurricane Allen in 1980, highway patrol officers could not locate the public official responsible for signal timing along a major evacuation route, so that evacuation traffic was stalled for the duration of the red signal at several locations, even though cross traffic was minimal at the time of the evacuation.
- Encourage "First Auto" Use. It is essential that public information broadcasts emphasize that households with more than one auto use only their first auto to evacuate. All of the crisis relocation plans reviewed in preparing this report assumed that households would restrict themselves to a single auto. Given the importance of the auto in today's culture, however, and the amount of money Americans have invested in their cars, this assumption could be tenuous. In Mississauga, where there was no threat to autos left behind, the average number of vehicles used to evacuate was 1.24 vehicles per household (Reference D-3). If this experience holds true during crisis relocation, the number of cars on the road will increase by 24% over planned levels, and available road capacity will be decreased accordingly.

3.5.3 Contingent Measures: Wrong Way Flow

One of the most obvious and most often suggested means of increasing roadway capacity in times of emergency is to convert all highways to one-way outbound movement. Use of the wrong side of a freeway or highway could conceivably double its capacity, and, just as important, double the number of entry ramps available in areas of concentrated population. However, the establishment of wrong-way flow on routes where contraflow procedures are not generally used presents a difficult, time-consuming, and potentially dangerous departure from ordinary procedures that is not always desirable and requires careful planning and implementation in those instances when it is necessary. The case against adapting a risk-area's freeway system to outbound flow has been well put by Hubenette, who observes that:

"The initiation of wrong-way flow would be difficult and time consuming. Sequential phasing would have to be developed so that upstream on-ramps were closed and traffic on the freeway directed off at certain off-ramps. This ramp closure and freeway clearing would involve physical control to guarantee success. The reliability of signs to perform the task is doubtful, since 100% clearing of the freeway would be required. One car proceeding in the direction opposite to the heavy flow could completely block the freeway by causing one major head-on collision.

Only after the freeway had been completely cleared could the wrong-way flow be initiated. A second series of signs or other control devices would be required to initiate the flow. Since the wrong-way flow would follow the initiation of directed evacuation, it would be impractical to make specific assignments to the wrong side of the freeway unless a rigidly controlled evacuation were planned. That is, it would be impractical to advise a portion of the population to wait until the freeway was clear before they started their movement operation. If specific assignments could not be made, use of the wrong side of the freeway would depend solely on traffic control devices or manual control by a uniformed officer.

The geometrics of existing off-ramps are such that they tend to make a wrong-way turn difficult. The paths traveled by vehicles attempting to use the off-ramps as on-ramps would be awkward. Also, since motorists would be proceeding in the wrong direction, they would have to use on-ramps as off-ramps. The terminals of most on-ramps at the street intersection are such that it would be difficult to turn onto the street in the proper direction." (Reference A-6)

The objections cited by Hubenette are not the only problems with one-way outbound flow. Even during the three-day relocation period, traffic flow requirements will not be exclusively one-way outbound. Essential intercity freight movements will continue to flow into and around risk areas, critical workers will have to commute, buses must return for additional passenger loads, and some intercity passenger movement may exist. In addition, maintenance of two-way flow on all roads will provide ready access from the reverse direction to stalled and abandoned vehicles in the outbound evacuation lanes. In view of the difficulties and potential dangers associated with wrong-way flows and the desirability of maintaining two-way flows on intercity routes, SYSTAN's earlier guidance included the wrong-way flows on freeways, "should be attempted only in instances where they are commonly employed to deal with peak commute problems, or as a last resort in areas in which the existing road network capacity is clearly inadequate." (Reference A-1)

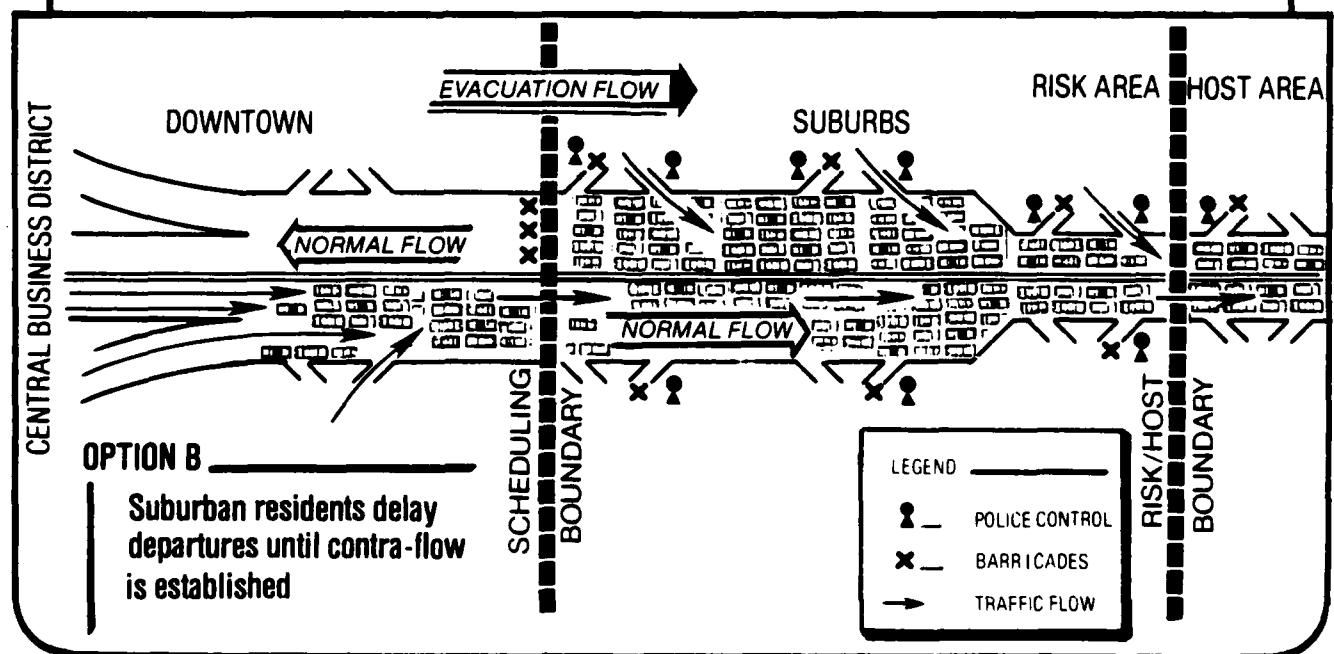
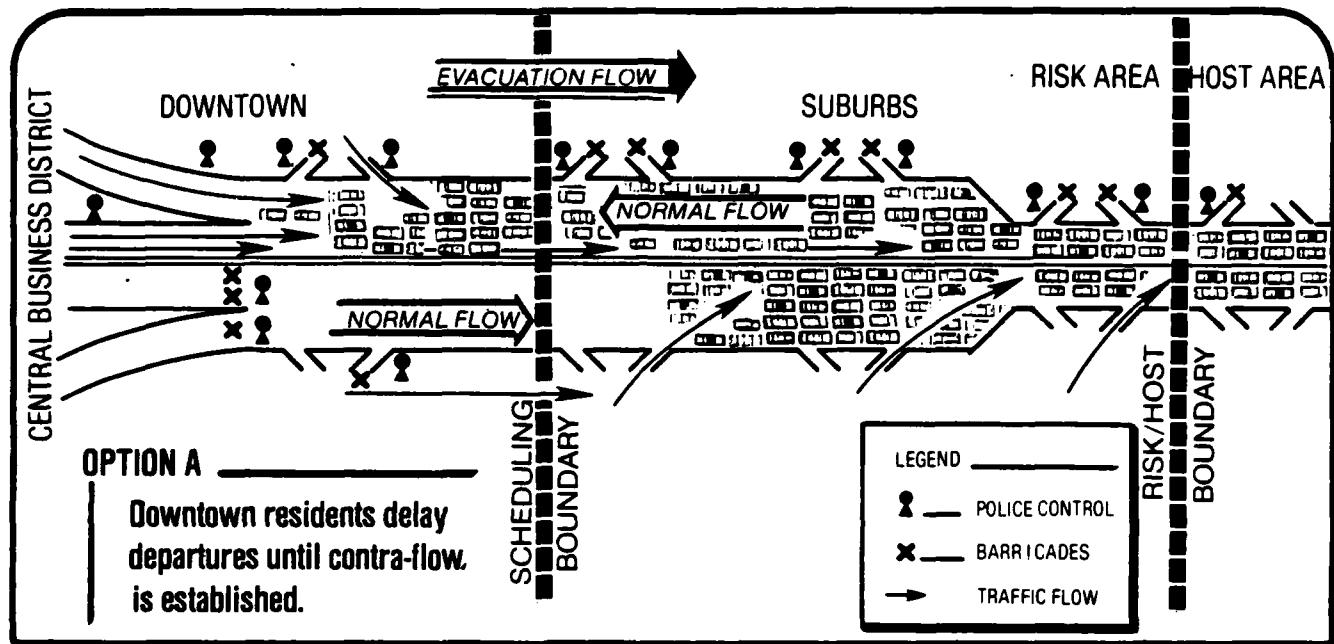
A review of the risk-area plans for a number of cities suggests that there are likely to be several U.S. risk areas whose road networks are inadequate to support crisis relocation. That is, several risk areas are likely to be faced with the "last resort" option of establishing wrong-way flow along evacuation routes. In an attempt to provide additional guidance for these cities, several traffic engineers and NCP planners were interviewed regarding the pros and cons of potential strategies for establishing wrong-way flow.

What Cities Need Wrong-Way Flow? Most traffic engineers agreed that the problems identified above represented real and serious stumbling blocks, but felt that, given enough time and manpower, they could be surmounted in case of emergency. The consensus of opinion was that at least half a day would be needed to establish wrong-way flow under crisis relocation conditions. Hence, any city which can project average evacuation times under 12 hours (i.e., Plattsburgh, Augusta, and San Antonio, from Exhibit 2.2) should not plan to attempt any freeway lane reversals. In fact, the establishment of wrong-way flow is likely to be of marginal value in cities which can project average evacuation times between 12 and 24 hours using only existing outbound lanes. In such cities, public safety personnel are probably best employed in keeping traffic moving through bottlenecks. When a city projects average evacuation times approaching 24 hours (i.e., St. Paul and Puget Sound areas in Exhibit 2.2) the possibility of wrong way flow should be considered. Wrong-way flow should only be considered seriously by cities which are willing to develop departure schedules for risk-area residents, since the establishment of wrong-way flow will generally require that some population groups delay their departure while reverse-flow lanes are set up.

Whose Departures Will Be Delayed? Several options exist in establishing wrong-way flow along a segment of freeway. One of the most basic choices is depicted in Exhibit 3.14. The exhibit depicts a narrowing length of freeway leading from the central business district of a risk area to a host area. At least two options exist for establishing wrong-way flow along the route. Under Option A, the entire

EXHIBIT 3.14

SCHEDULING OPTIONS FOR CONTRA-FLOW FREEWAY TRAFFIC



length of inbound freeway is converted to wrong-way flow, and downtown residents are asked to delay their departures until the reverse-flow lanes are operational (see Exhibit 3.14). Under Option B, a shorter length of freeway is reversed, and downtown residents are allowed to use the regular outbound lanes while suburban residents wait for reverse flow. There are several reasons for preferring Option B to Option A:

- a) Option B requires the reversal of a shorter length of freeway, and hence less time and fewer personnel commitments at the barricades.
- b) Under Option A, downtown residents will be staring over barricades at empty outbound freeway lanes, and the temptation to break the barricades will be great. Under Option B, suburban residents arriving at barricades will see outbound lanes filled with stop-and-go traffic. The sight of the clogged freeway should be at least as discouraging as the barricades, and help to convince the residents to wait for the reversal of the inbound lanes.
- c) Under Option A, downtown residents will be able to use surface streets to join suburban residents at the outbound ramps reserved for early departures. Under Option B, suburban residents are not likely to travel deeper into the risk area (away from the host area) to find a usable entry ramp if they want to depart before their allotted time.

In addition, suburban residents living near the host area boundary are more likely to be aware of alternative routes to the host area which do not require freeway access. All in all, there appears to be a powerful argument for emulating the Mississauga experience and allowing the inner city (generally those most at risk) to evacuate first when departures must be scheduled and wrong-way flow needs to be established.

Additional Concerns. In cases where a freeway has more than one inbound lane through its bottleneck, cities might be tempted to retain inbound flow on one of these lanes while reversing flow in adjacent lanes. Traffic engineers tended to discourage such an approach, fearing that the increased accident potential and additional ramp complexities would make an already complicated situation unworkable. The engineers interviewed much preferred an "all-or-nothing" approach to freeway lane reversal.

Engineers also noted that wrong-way flow should be extended the full length of any bottlenecks, perhaps even to entry control stations on the far outskirts of the host area. This would eliminate any problems merging the outbound flows of traffic, and allow the entry control point and its holding area to serve as a buffer for inbound traffic.

In addition to freeways, cities may also consider establishing wrong-way flow along expressways and surface streets designated as evacuation routes. Most of the concerns discussed in this section must still be addressed. While individual surface-street intersections offer

fewer merging problems than freeway ramps, the number of intersections that need to be barricaded or controlled in establishing wrong-way flow along surface streets far exceeds the number of control points along a limited access freeway.

3.5.4 Contingent Measures: Occupancy Restrictions

One way of easing traffic problems is to require that all automobiles using designated routes at certain times have a minimum number of occupants (i.e., two or three persons per car). There are several obvious problems with such an approach, not the least of which is that it would require the presence of enforcement personnel at all access points. These personnel would have to inspect individual vehicles and be willing and able to either turn away unqualified drivers or to form "instant carpools" from a supply of such drivers at holding areas.

This would create traffic tie-ups at inspection points, as well as hostility among drivers who are unable to meet the required occupancy standards. Occupancy restrictions during crisis relocation are recommended only on installations where a separate right-of-way already exists to accommodate carpools (such as the El Monte Busway in Los Angeles or the Shirley Highway in Washington, D.C.). Even in these cases, it is suggested that no attempt be made to screen entering vehicles and that enforcement activities be minimal.

3.5.5 The Role of Public Safety Personnel

Public safety personnel will contribute in a number of ways to activities designed to expand the capacity of evacuation routes. They should:

- Permit autos to use roadway shoulders where merging problems can be avoided;
- Obtain keys to all signal boxes along evacuation routes within their jurisdiction;
- Participate in planning for the implementation of wrong-way flow measures;
- Clear traffic along inbound routes designated for reverse flow; and
- Assign officers as needed to enforce ramp barricades and direct traffic onto reverse-flow freeways.

3.6 FLOW MAINTENANCE

It is imperative that public safety officers keep traffic moving during crisis relocation. Slowdowns and stoppages require immediate police attention and control if a continuous flow of traffic is to be maintained. Officers should focus their attention on the bottleneck segments of evacuation routes, since any reduction of capacity along these segments will directly affect the time required to clear the risk area. This section addresses four key elements essential to the maintenance of a steady flow of traffic along outbound evacuation routes:

1. Dynamic surveillance;
2. Routine patrol;
3. Incident response; and
4. Destination controls.

3.6.1 Dynamic Surveillance

If the highways leading from the nations large risk areas are to be used to their fullest capacity, plans for dynamic surveillance and control of traffic must be developed that include:

- Fixed surveillance devices;
- Trained observers at key surface locations;
- Aerial surveillance;
- Strategically placed emergency response teams; and
- Control of key access points to main evacuation routes and potential detours.

Each of these elements must be linked to a control center through a suitable communications network. The control centers must in turn be able to assimilate and interpret surveillance reports, issue operating instructions, and communicate effectively with drivers and would-be drivers.

Most major cities already have the central spine of the required command and control centers in place to deal with the day-to-day problems of traffic congestion. However, a multitude of planning and liaison functions need to take place before this spinal column can be expanded to make the neural connections needed to support crisis relocation. To name just a few, advance arrangements need to be made with "eye-in-the-sky" traffic observers (generally operated by local

radio stations), communications channels linking several diverse jurisdictions and entities need to be established, broadcasting requirements need to be settled, deployment plans for personnel and equipment need to be prepared, and alternative routing plans capable of bypassing congested bottlenecks need to be worked out. In cases where alternative routes and flow patterns can be identified, procedures should be developed for rerouting evacuation traffic around traffic jams and developing bottlenecks. Outbound flow should be monitored by aircraft, so that timely reports on traffic conditions can be relayed to motorists and accident reports can be passed along to enforcement personnel. In the interests of conserving personnel, responsibility for complying with alternative routing suggestions can be left with the individual motorists. However, traffic control officers should be assigned to a few key traffic control points with authority to detour all or part of the traffic traveling on primary routes as congestion develops.

3.6.2 Routine Patrol

With a few exceptions, routine patrol activities along evacuation routes will resemble normal day-to-day patrols. Patrol efforts should be concentrated along bottleneck segments, since any breakdowns of flow along these segments will do disproportionate damage to the evacuation process. Police patrols should be assigned to other segments of roadway on the basis of traffic volumes and anticipated trouble spots. Where possible, motorcycle patrols should be used to improve access in areas of severe congestion. Motorcycles will be particularly important along route segments which have been converted to one-way outbound traffic.

For safety reasons, many police patrols do not currently carry additional supplies of gasoline. Rather, vehicles are equipped with gasoline transfer drivers. Under crisis relocation conditions, police patrols should carry two-gallon cans of gasoline, to minimize the amount of time required in assisting out-of-gas motorists. As an added precautionary measure, vehicles regularly making the reverse run over the evacuation route (i.e., buses, vans, and carpools carrying critical workers) should be supplied with two-gallon cans of gasoline. These cans could be given to out-of-gas evacuees in outbound lanes and provide an additional measure of fuel insurance for commuting workers and others making regular trips upstream.

3.6.3 Incident Response

During crisis relocation, response to traffic incidents such as accidents, stalls, or spilled loads, will be similar to normal emergency response activities, except that added emphasis should be devoted to removing blockages and keeping traffic moving. Tow trucks should be stationed at entry control posts and other staging areas along the evacuation routes. Specially equipped incident response vehicles

staffed by highway maintenance personnel should also be stationed at key points along the evacuation routes.²

Advance plans should be made for handling stalled and disabled vehicles and for responding to accident reports in an expeditious manner during the relocation period. Detailed procedures are needed for reaching disabled vehicles, for clearing them off the evacuation highways and for removing them for repair or disposal. Where two-way flow has been maintained along an evacuation route, access by tow trucks from "downstream" maintenance facilities and gasoline stations will be relatively straightforward. However, vehicles disabled on one-way bridges, in tunnels or along stretches of one-way-only roads will be very difficult to reach as traffic piles up behind them.

During crisis relocation incident-response teams should focus on the quick removal of roadway blockages. Overturned trucks and disabled autos should be similarly shoved to the side of the road. Attempts to salvage loads, remove wreckage, and tow disabled vehicles to repair stations should be postponed until the evacuation has been completed and traffic conditions have eased.

Travelers in disabled vehicles also need to be dealt with. They can wait for repairs; they can be assigned to other vehicles; or they can be reassigned to different destinations. Unless they wait for repairs some or all of their baggage must be removed from the disabled vehicle and disposed of in some fashion. Helicopter surveillance and regular police patrols over sections of the route will facilitate rapid

² The California Department of Transportation has established incident response teams made up of experienced traffic operations personnel in major metropolitan areas (References F-6 and F-7). The focal point of team activities is an incident response truck with changeable message signs. Each truck also contains, at a minimum, the following equipment:

- a) Eight channel scanning transceiver with a minimum of four CALTRANS frequencies.
- b) Highway Patrol scanner - eight or ten channels.
- c) AM Radio - to monitor sigalerts and traffic advisories.
- d) Safety equipment - hard hat, red vest, first aid kit, flashlight, fire extinguisher, raingear, etc.
- e) Freeway detour signs - both 30" X 30" metal and 4' X 4' plastic coated fabric type.
- f) 4' X 4' "prepare to stop" warning sign.
- g) Quadpods for the 4' X 4' signs.

response to accidents and stalled vehicles and will lessen the problems associated with them.

3.6.4 Destination Controls

One aspect of crisis relocation traffic which is often overlooked is the importance of adequate traffic control measures at host-area destinations. It is essential that ample off-highway parking be provided near reception and care centers. In addition to parking lots, nearby fields and other suitable spaces should be striped to accommodate the efficient parking of arriving vehicles. Under no circumstances should queues of arriving vehicles be allowed to extend backward onto main evacuation routes. This possibility affords more of a threat to the limited highway capacity in most host areas than the possibility of stalled vehicles or accidents, and will be harder to correct if it does occur.

To facilitate the movement of host-area traffic, signs should be provided to reassure motorists that they are on the proper routes. Exits to reception areas should be clearly designated, directions to reception center parking should be clear and precise, and volunteers should be available to direct parking at reception centers. Finally, Hubenette cautions that,

"...signing will be necessary to designate when reception centers are filled to capacity, so that motorists may continue along the highway to the next available location without having to wander from reception center to reception center." (Reference 8-1)

3.6.5 Contingent Measures: Round-Robin Convoys

In the past, highway patrol officers have had some success with the use of a convoy technique known as a "round-robin" in which officers act as escorts for platoons of automobiles. The technique has been used effectively both to enforce a desired speed, to negotiate severe traffic bottlenecks under hazardous driving conditions, and to ease oncoming motorists into a queue when the end of the queue is obscured by terrain or road geometry. Upon negotiating the bottleneck, officers allow the platoon to proceed unescorted and return to escort subsequent platoons.

h) Flares and a few traffic cones.

Team members position truck-mounted changeable message signs upstream of any incident to notify the public of conditions ahead and of suggested diversion routes. Trail-blazer and reassurance signing is placed along the detour routes to expedite flows.

and limits the spread of shock waves through traffic when incidents occur, observers note that the use of platooning causes the vehicle throughput per unit time to drop significantly below bottleneck capacity. Since round-robin convoys impose intensive patrol requirements on public safety agencies, and at the same time reduce effective roadway capacity, their use is not recommended for negotiating bottlenecks under crisis relocation centers. However, such convoys may be needed to warn oncoming motorists of the need to slow down when approaching the end of a queue of autos.

3.6.6 The Role of Public Safety Personnel

The all-important task of keeping traffic moving during an evacuation falls predominantly on public safety personnel. Before and during crisis relocation they should:

- Prepare deployment plans for personnel and equipment;
- Develop alternate routing plans capable of bypassing congested bottlenecks;
- Station officers at key surveillance points;
- Maintain aerial surveillance of all traffic routes;
- Prepare and transmit traffic advisory messages;
- Direct traffic onto detours in response to incidents, changing conditions, and traffic advisory messages;
- Patrol all segments of evacuation routes, particularly potential bottlenecks;
- Apprehend motorists exhibiting unsafe behavior;
- Respond to accident reports;
- Request tow trucks, motorist-aid units, and incident response teams as necessary;
- Clear stalled and disabled vehicles off the evacuation roadway as soon as possible;
- Reinstate traffic flow where congestion and/or accidents have caused stoppages;
- Assist stranded motorists and passengers;
- Carry gasoline for out-of-gas motorists;

- Review host-area parking plans to make sure that ample parking is available and that arriving vehicles are not likely to queue backward onto main evacuation routes; and
- Direct the flow of vehicles to host-area parking facilities.

4. ORGANIZATION AND STAFFING

This chapter discusses organizational concerns involving jurisdictional boundaries and command structures, and addresses the problem of estimating staffing requirements for crisis relocation. A final section lists unanswered questions and proposes topics for future research efforts.

4.1 ORGANIZATION

Control of highways during emergencies requires the participation and close cooperation of state transportation agencies, state and local police organizations, and local highway/public works departments. In most states the state transportation agencies or highway departments have been assigned responsibility for emergency highway traffic regulation. The authority for directing and enforcing these regulations is typically delegated to the commanding officer of the state police agency.¹

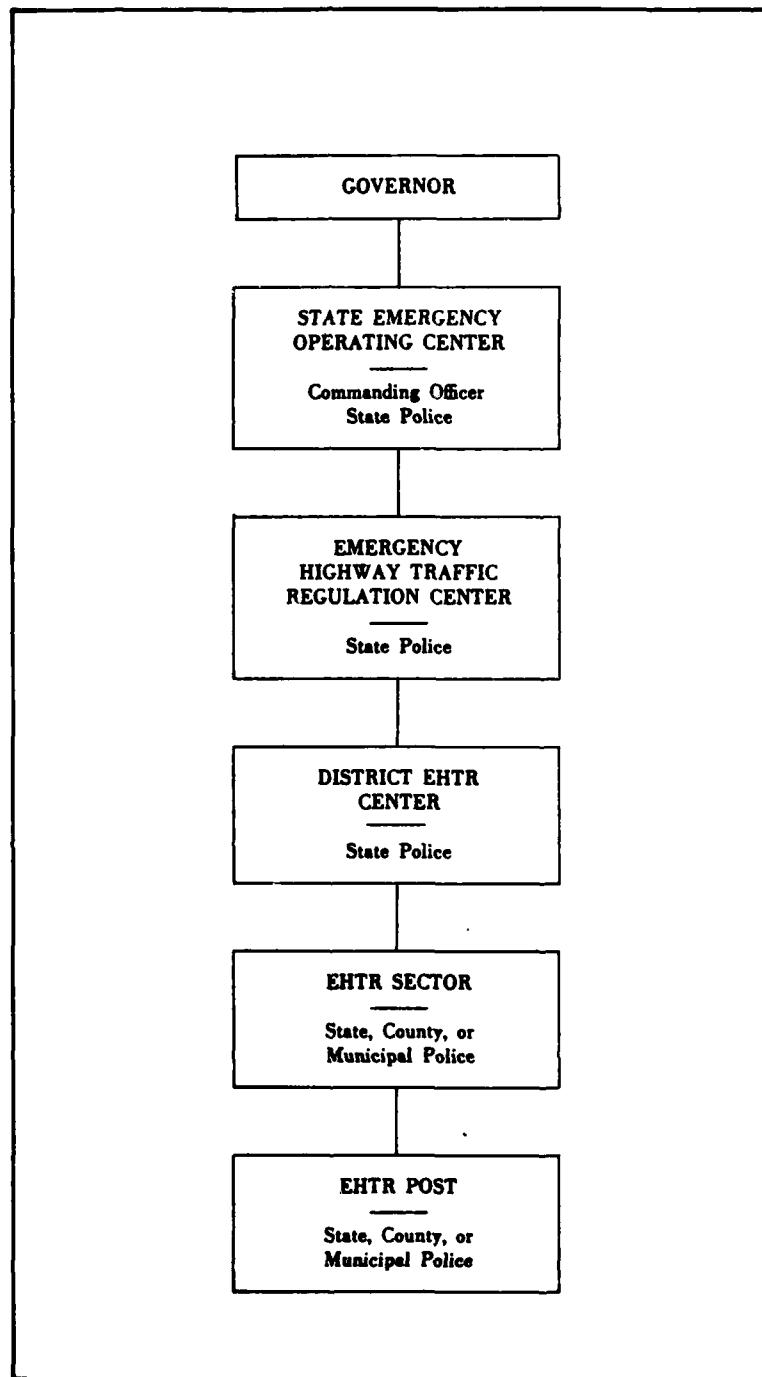
4.1.1 Chain of Command

Exhibit 4.1 displays the simplified chain of command recommended by the FHWA's Guide for Highway Traffic Regulation in an Emergency (Reference C-5) for the purpose of assigning responsibility, delegating authority, and establishing lines of communications in the EHTR organization. Although this chain of command is eminently logical and appears self-evident, it contains several implications worthy of comment:

1. The success of the police mission will depend upon coordination and cooperation among state, county, and municipal police. This cooperation may be enhanced by using already-existing groups such as state associations of police chiefs or the enforcement committees of state safety councils.
2. Primary evacuation routes are likely to be state or federal highways which cross several county and municipal jurisdictions. The decentralized nature of state police operations, and the experience of the state police in handling nationwide situations

¹ Because each governor has the perogative of designating the agencies responsible for emergency highway traffic regulation and enforcement, precise police responsibilities may vary somewhat from state to state.

Exhibit 4.1
POLICE "CHAIN OF COMMAND" FOR
EMERGENCY HIGHWAY TRAFFIC REGULATION



Source: Reference C-5

crossing jurisdictional lines makes the state police agencies the logical choice for the lead role in controlling traffic under crisis relocation conditions.

3. During the evacuation phase of crisis relocation, county and local police officers, sheriff's deputies, and road public works department staff may be assigned to the District Commander of the State Highway Patrol for traffic regulation purposes. It is anticipated that these local personnel will be employed in the vicinity of their original jurisdiction, under the coordination and supervision of the State Highway Patrol Commander. When the evacuation has been completed, all personnel and equipment, except those assigned to ongoing EHTR posts, will be returned to the control of their jurisdictions.
4. It is essential that a clear chain of command be established and that all enforcement agencies recognize and adhere to it. The chain of command for traffic control should spell out all organizational relationships and should be made a part of all relevant crisis relocation documents. Official evacuation plans may require that certain municipalities delay their departure for the common good. The municipal police within such jurisdictions may be asked to undertake enforcement actions which are decidedly unpopular with their constituents, such as staffing barricades or otherwise denying access to evacuation routes.

4.1.2 Communications

Communications for traffic control are likely to be fragmented because of the participation of diverse agencies from different jurisdictions. Many of the agencies providing personnel, vehicles, and equipment within a control sector will not have common radio frequencies or integrated day-to-day radio communications. Incompatibility of communications equipment was one of the chief frustrations cited by the police officers responsible for the recent evacuations of Mississauga and Corpus Christi (References D-3 and H-6).

Because effective movement control will depend on an integrated field communications network, care should be exercised to avoid assigning radio-equipped vehicles outside their area of normal operations. Wherever possible, forces assigned from other jurisdictions should be equipped with portable radios using local frequencies. Failing thus, personnel from other jurisdictions with incompatible frequencies should be paired with local officers having compatible communications equipment. To minimize communications problems, planners have proposed that each field unit involved in the movement control operation maintain communications with their normal day-to-day communications center, which will retransmit, as necessary, information and messages to the nearest Emergency Operations Center with comprehensive communications facilities (Reference C-5).

Local and district operations centers will be linked by both radio and telephone to the state center for Emergency Highway Traffic Regulation. The furnishings and functions of this center are listed in the FHWA's EHTR Guide (Reference C-5). The Guide notes that each state should establish current emergency communications links with contiguous state highway departments, and that each state plan should "contain an explanation of its communication capability, including its ability to contact the agency in the adjacent states which would be responsible for emergency highway traffic regulations."

4.2 PERSONNEL PLANNING

Few existing crisis relocation plans address the problem of personnel planning for public safety agencies. Of the plans reviewed for this report, only those for smaller risk areas (i.e., Plattsburgh and Augusta) attempted to estimate staffing requirements for traffic control at key intersections. Plans for larger areas rarely even attempted to identify key traffic control points.

It seems clear that traffic control during the evacuation phase of crisis relocation could easily consume all the available highway patrolmen and most of the local police in the vicinity of any major risk area. Traffic control and parking at major sporting events typically require the attention of most of the police in the affected municipalities (Reference E-2). As many as fifty highway patrolmen were needed just to control the traffic exiting from two ramps in the vicinity of the UNUSON festival held over a three-day weekend during the summer of 1982. Since the requirements for public safety personnel are likely to exceed the number of experienced personnel available for traffic control duties, personnel planning for crisis relocation must document the staffing requirements associated with each control activity, attempt to prioritize activities, and explore labor-saving options for reducing the number of personnel needed for traffic control.

4.2.1 Personnel Estimates

- General Observations. During crisis relocation, public safety personnel should automatically be assigned to 12-hour shifts. The Mississauga experience cautions against throwing all available personnel into the breach during the first 12-hour shift. The Chief of the Mississauga Fire Department, Gordon Bently, warns of the following problems with a massive early call-up of public safety personnel:

"If you yield to the temptation to use all these men...or keep them standing by in reserve, this can create a problem at shift change when you need a fresh complement of fresh men at the fire scene

and to run the fire halls. In other words, if a chief yields to the natural temptation to pour in everything he's got for a massive first strike, rather than think ahead eight or ten hours, he runs the risk of fatigue setting in to his whole department at the same time."

(Quoted in Reference B-3)

At least half of the available public safety personnel could profitably use the first 12 hours following the evacuation order to see that their families are safely relocated.

In addition to the automatic employment of 12-hour shifts, another strategy which could free additional personnel for essential traffic control duties is the assignment of only one officer to each patrol vehicle.

- Entry Control. Traffic control officers should be assigned in teams of two to control entry at key intersections along major evacuation routes. One officer will direct traffic for a period of two hours, while the other officer monitors the evacuation from a patrol vehicle, reporting to the Emergency Operations Center every 30 minutes and at any other time a serious problem develops. After two hours, the officers should trade positions. The Plattsburgh Crisis Relocation Operations Plan (Reference B-4) lists the following duties for the two officers:

"The Traffic Control Officer while directing traffic in the intersection will promote the orderly flow of evacuating vehicles by:

- a) directing evacuating vehicles through the intersection
- b) controlling turning movements onto the main evacuation corridor from the intersecting roads
- c) clearing tie-ups
- d) preventing movement and turning not consistent with the evacuation flow direction
- e) encouraging brisk yet safe movement through the intersection by not assisting people seeking information but simply directing them through the intersection. Autos with windshield identification stickers indicating that they are on the wrong evacuation route will not be stopped but directed through with the other vehicles."

"The Traffic Control Officer while assigned to monitoring in a vehicle will:

- a) regain his physical strength for his/her next 2 hours intersection duty
- b) make a general count of the vehicles proceeding through the intersection (including average number of people in vehicles)
- c) report count and general intersection status to Emergency Operating Center every 30 minutes via radio
- d) report serious problems to the command post as they arise
- e) receive instructions from the Emergency Operating Center
- f) assist intersection officer in difficult situation if needed
- g) monitor general non-highway situation in his/her physical view and report any serious problems to the Emergency Operating Center."

Complex intersections handling large traffic volumes may require additional teams of two officers. Every risk-area plan should identify and prioritize those key traffic control points requiring officer presence, and stipulate the organization responsible for providing officers. In general, the closer an entry point is to the bottleneck of an evacuation route, the more critical the need for officer control. Ideally, barriers preventing entrance to main evacuation routes should be manned. However, if barriers are sufficiently formidable, aerial surveillance should be able to detect potential problems in time for surface patrols to respond. Minimum restrictions need be placed on neighborhood and local collector streets removed from major evacuation routes.

Perimeter Control. Public safety personnel have the lead responsibility for securing the risk area and intercepting and interrogating incoming traffic. The location of perimeter control posts has been discussed in Section 3.4.1. The medfly infestation afflicting California's Santa Clara Valley in 1981 provides timely and useful insights into the number of public safety personnel required to cordon off a major metropolitan area. To check the spread of the Medfly, the California Highway Patrol cordoned off the infested area, and periodically inspected all outgoing vehicles for agricultural products that might harbor the insect's spoor. Thirteen inspection sites were created along highways leading from the San Jose and San Francisco/Oakland metropolitan areas, and over five million vehicles were inspected in the course of the quarantine. The officer responsible for staffing these inspection points found that they required a minimum of two officers per lane of incoming traffic. When traffic was particularly heavy, three officers were needed per lane.

In addition to the officers required for traffic control and inspection, special signing and two additional officers were needed along each route to make oncoming motorists aware of the existence

of the inspection queue. The additional officers formed round-robin expeditions to ease oncoming motorists into the queue when the end of the line was obscured by terrain, curves, or other highway features.

Patrol Duty. Many patrol duties will be similar to those encountered in the course of normal commute traffic. Patrol vehicles should concentrate on the bottleneck portions of evacuation routes. Where possible, motorcycle patrols should be used to improve access in areas of severe congestion. Only one officer should be assigned to each patrol car.

Within metropolitan areas, normal beat definitions should be retained during crisis relocation for ease of planning and assignment. Such beats typically range from three to ten miles in length (Reference C-3). It is likely that normal beat lengths will have to be shortened along rural portions of evacuation routes. The typical rural beat length on limited-access freeway can range from 10 to 40 miles and is likely to be too long for a single vehicle under congested crisis relocation conditions. Beat lengths should be designed so that patrol vehicles pass by a single point (in the same direction of travel) at least once every two hours (Reference C-3), and converge along the bottleneck segments should be more frequent.

The following formulas may be used to compute beat lengths and personnel requirements.

$$\text{Patrol Units Needed} = \frac{2(\text{Number of Passes})(\text{Length of Roadway})}{12(\text{average speed})}$$

$$\text{Beat Length} = \frac{12(\text{Average Speed})}{2(\text{Number of Passes per 12-Hour Shift})}$$

$$\text{Beat Length} = \frac{6(\text{Average Speed})}{(\text{Number of Passes per 12-hour Shift})}$$

The average patrol speed recorded by a sampling of six state police agencies under normal operating circumstances was 20 miles per hour (Reference C-3). This speed took into consideration the time required to complete all administrative tasks; time in court; the time spent on enforcement, accident coverage; motorist services; patrol time; non-traffic duties; offering assistance; and various miscellaneous tasks. It is likely that the congestion encountered under crisis relocation conditions will reduce this average considerably. It should also be recognized that the above formulas are not necessarily usable in the case of limited access highways which have been converted to one-way outbound flow for crisis relocation. In this case, the calculation of the number of patrol units required must reflect the time required for patrol to return to their starting points for repeat passes. This time could be significantly lengthened if the return route is roundabout.

Destination Control. The importance of clearing traffic from the evacuation route expeditiously once vehicles have reached their destinations cannot be overemphasized. Two traffic control officers should be assigned to each host-area exit to keep traffic moving (not to answer inquiries). The two officers should operate in two-hour shifts, as in the case of officers assigned to entry control. In addition, at least one traffic control officer should be assigned to each major parking area within the host area. These parking lots provide one example of an instance where a number of volunteers may be available and able to help direct parking activities.

4.2.2 Labor-Saving Options

In most major sites, requirements for traffic control personnel and equipment may exceed the available supply of uncommitted public safety officers. Certain actions may be taken to reduce the number of officers employed in traffic control activities. Options to be considered by planners should include:

- Passive controls;
- Auxiliary personnel;
- Private and volunteer equipment;
- Procedural improvements; and
- Selective enforcement.

- Passive Controls. The use of passive controls (i.e., barricades) wherever possible will help to reduce the need for public safety personnel at certain control points. As discussed earlier, however, (see Section 3.3) any such barricades will need to be substantial (for example, constructed from heavy equipment rather than movable saw-horses and cones) and any unmanned barricades must be checked regularly by aerial surveillance and surface patrols for signs of trouble.
- Auxiliary Personnel. In general, professional police officers should be used whenever possible so that a minimum of extra training is necessary. However, some tasks (the staffing of communications outposts, and the control of traffic in host-area parking lots, for example) may be allocated to auxiliaries who have received some training through volunteer organizations or other interest groups. These auxiliaries can free professionals for control activities requiring direct contact with evacuees.

The possibility of using auxiliary personnel in emergency circumstances was viewed with mixed emotions by the planners and public safety personnel interviewed in the course of this study. On the one hand, most planning manuals (References C-4 and C-6) recommend the use of auxiliary personnel. One movement plan (Plattsburgh, Reference B-4) proposes to accomplish traffic control during relocation with volunteers trained in three-to-nine hour sessions during the crisis-buildup phase preceding the evacuation order. On the other hand, most full-time police officers interviewed during the study viewed the use of auxiliary personnel with some skepticism, and stressed that their duties should be limited to support functions.

As a practical matter, it was generally recognized that public safety personnel will certainly need all the help that they can get if crisis relocation is to succeed. Hence, they should plan to seek out and use auxiliary personnel in certain controlled situations. Situations in which police departments might profitably use volunteer support to traffic control duties during crisis relocation would include:

- a) Assistance with host-area traffic control, particularly parking
- b) Administrative support for inbound checkpoints on the perimeter of risk and host areas (i.e., in issuing entry permits);
- c) Staffing of communications outposts; and
- d) Surveillance and communications support for on-duty traffic officers.

In order to make the most efficient use of volunteer personnel, public safety agencies should:

- a) Maintain lists of organizations and individuals capable of joining reserve units or mobilizing volunteer support;
- b) Provide adequate training for the tasks assigned to auxiliary personnel;
- c) Make sure that auxiliary personnel are issued proper identification;
- d) Emphasize that auxiliary officers cannot exercise the powers of a police officer until they are given those powers by appropriate authority. Even then, powers should be limited by clearly defined restrictions;
- e) Try to pair auxiliary personnel with experienced police officers;
- f) Avoid placing auxiliary personnel in positions of direct confrontation with evacuating citizens;

- g) Avoid planning to use persons who hold reserve positions in the military service or have other critical skills.
- Private and Volunteer Equipment. Motorcycle patrols could be used to advantage in the tight traffic jams accompanying crisis relocation. In addition to regular law enforcement equipment, Reference C-1 suggests that additional motorcycles could be obtained from dealers or citizens. This reference also suggests that machines not equipped with radios could be made part of the communications system by the addition of portable public safety or CB radios and the use of a commercial broadcast station in communication with the portable broadcast receivers. Finally, the authors observe that

"The Radio Emergency Associated Citizens Teams (REACT) located throughout the nation are presently assisting public safety agencies with highway-related situations on an hour-to-hour basis and will be an invaluable asset to the crisis relocation operation."

(Reference C-1)

Public safety personnel should maintain inventories of private resources which could be employed in a widespread emergency such as crisis relocation. Resources should be itemized as to type, location, method of contact, public use, limitations, accessibility, and other pertinent information. Such resources should include:

- a) wreckers;
- b) heavy construction equipment and operators;
- c) vehicle fuel and service outlets;
- d) motorcycle and car dealers;
- e) equipment service centers;
- f) communications equipment and amateur radio operators; and
- g) motor fleet operators.

- Procedural Improvements. The importance of establishing efficient operational procedures at control points cannot be overestimated. The officer responsible for establishing the medfly vehicle inspection cordons in Santa Clara Valley noted that personnel requirements dropped from three officers to two officers per lane in many cases once routine operating procedures had been established. Unfortunately, the heaviest demands for traffic control officers will occur during the first day of crisis relocation and there will be little opportunity to establish routines or learn from experience before the evacuation is completed.

An evaluation of the individual elements of a patrol officer's day (Reference C-3) suggests that there are relatively few routine duties that might be abandoned in time of emergency to free patrol officers for more important tasks. If anything, the time consumed by such essential activities as accident response and lane clearance will increase markedly during crisis relocation.

- Selective Enforcement. It could be difficult and counterproductive to vigorously enforce all restrictions on scheduling, departure times, occupancy requirements, etc. Rather, it may be sufficient to advertise such restrictions and enforce them selectively, freeing enforcement personnel to respond to accidents, control access at key entry points, and accomplish tasks having a more immediate impact on traffic flow. Enforcement personnel should not attempt to deny entry to evacuation routes on the basis of any criteria which demands individual vehicle inspection. Nor should traffic flows be stopped to redirect vehicles which have wandered onto the wrong exit routes.

4.2.3 Priorities

Some defections may be expected among even the most dedicated public safety personnel under crisis relocation conditions. Since the need for experienced police officers during evacuation is almost certain to exceed the number of local personnel available, even without defections, it is absolutely essential that planners and area commanders set clear priorities on the tasks to be assigned under crisis relocation conditions. Priorities must be established locally to fit local conditions, but certain general principles should be observed:

1. Surveillance and control of bottleneck areas on outbound evacuation routes is of predominant importance. In addition, enough traffic control personnel must be assigned to host-area destinations to make sure that arriving traffic does not back up onto the evacuation route.
2. The lowest order of priority should generally be assigned to traffic control on collector streets within the risk area. These streets will generally have sufficient capacity, and local congestion is not likely to affect the flow along critical outbound routes.
3. Perimeter control of inbound traffic is certain to be of less immediate importance than the maintenance of outbound flow. Some perimeter control tasks, such as driver interrogation and permit issuance, may be handled by volunteers or auxiliary personnel.

4.3 ADDITIONAL AREAS OF INVESTIGATION

The current study has highlighted several areas in which the existing level of understanding of traffic control measures needs to be expanded for crisis relocation planning. Questions which should be studied include:

- Investigations of Road Capacity;
- Exploration of Computer Models;
- Special Studies in Large Risk Areas; and
- Preparation of Simplified Transportation Planning Guidelines.

4.3.1 Road Capacity Investigations

The problem of specifying road capacity under evacuation conditions has haunted this study and past transportation studies performed by SYSTAN and others. Any attempt to estimate relocation feasibility in a populous area sooner or later turns on the question of "How many vehicles can we move over Route such-and-such in an hour? In 24 hours?" To date, there have been several diverse attempts to address this question, and these attempts have not always provided consistent answers. Yet a knowledge of road capacities under stress is essential to the successful development of useful crisis relocation plans. Traditional traffic engineering theory breaks down when congested conditions exist over long periods of time. Although this report has managed to shed a little more light on the road capacity questions (see Section 3.5) the problem still requires some basic research. Some of the approaches which might be taken to provide more definitive estimates of road capacity under stress are listed below:

- Assemble and interpret data on past evacuations in the face of hurricanes and other natural disasters;
- Identify instances in which prolonged conditions of congestion currently exist on roadways; and
- Assess the utility of computerized traffic simulation models in addressing the question of road capacity under stress.

4.3.2 Computer Models of Evacuation Flow

For several years, computer models have been available to accomplish the bookkeeping chores of route selection and vehicle assignment needed to evaluate traffic movements in large-scale networks. Simulation models are also available on a more limited scale to investigate the minute-by-minute consequences of dynamic disturbances in traffic flow (Reference G-3). During the current study, SYSTAN worked with Professor Adolf May of the University of California at Berkeley to adapt one such program to simulate traffic on a single outbound evacuation route and study the effect of alternative traffic control measures.

In addition to the single-route computer models developed at the University of California, several different node-link network models have been developed over the past three years for the purpose of simulating evacuations from areas in the vicinity of nuclear power plants (References G-1, G-3, and G-4). These node-link models have been developed in response to Nuclear Regulatory Commission guidance and focus on the task of developing evacuation time estimates and dynamic routing strategies in the immediate vicinity of nuclear power plants. However, the road networks simulated by these models are typically smaller than the networks that would be needed in the event of crisis relocation. The full range of available models should be investigated to determine whether any of them can be profitably adapted for use in the broader question of crisis relocation.

4.3.3 Special Studies in Large Risk Areas

The nation's largest risk areas are likely to have unique traffic control problems which will require explicit planning guidance. FEMA is currently initiating a pilot study (Reference A-5) to prepare guidelines and procedures for the transportation planning efforts required to support the crisis relocation of large risk populations.

4.3.4 Simplified Planning Guidelines

Contacts with NCP planners and reviews of early returns from the planning activity indicates that current planning guidance needs to be boiled down to simple, step-by-step procedures that specify explicitly what is required of each planner. One group of planners suggested that key elements of the planning process might be committed to videotape to simplify the indoctrination of new planners.

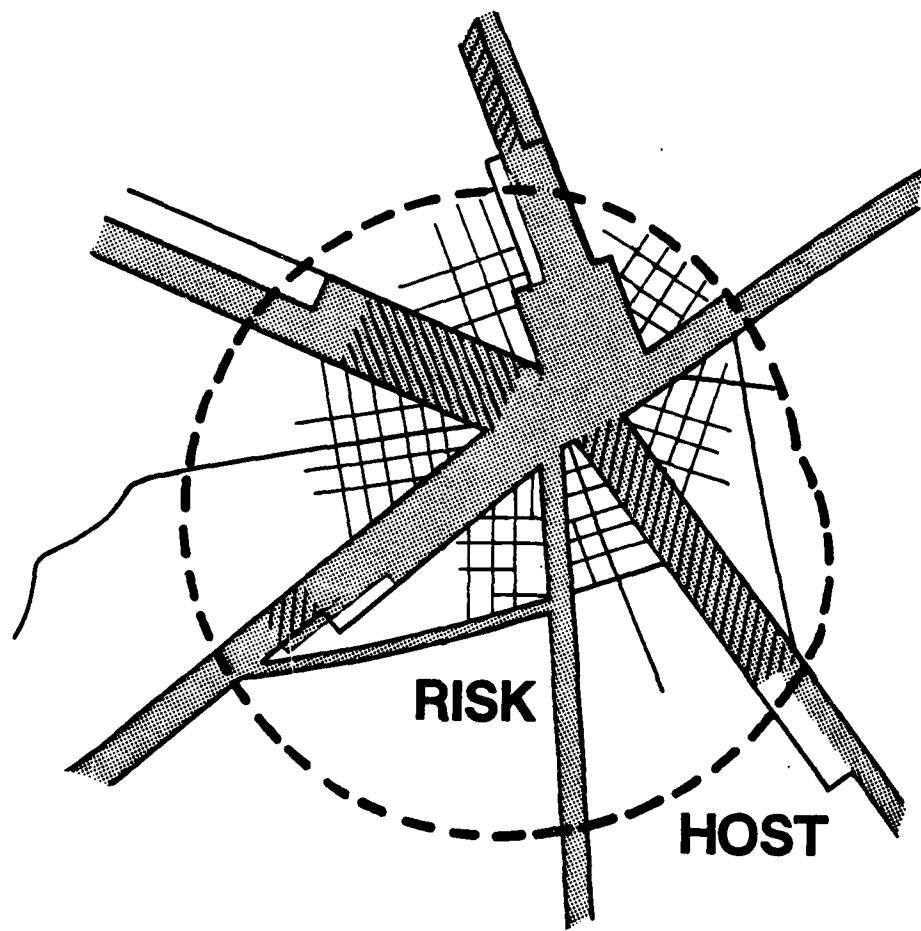
Appendix A

CRISIS RELOCATION GUIDELINES FOR PUBLIC SAFETY AGENCIES

CRISIS RELOCATION GUIDELINES

for

PUBLIC SAFETY AGENCIES



PREFACE

This appendix has been prepared as a companion volume for the report "Traffic Control Measures for Crisis Relocation" and is intended to summarize the traffic control measures likely to be needed under crisis relocation conditions, list the responsibilities of public safety agencies charged with implementing these measures, and provide staffing guidance for public safety personnel charged with assigning officers to traffic control duties during crisis relocation.

The guidance does not address the detailed actions of officers assigned to traffic control. The authors recognize that experienced police officers understand these actions better than researchers, and have no need to be told, for instance, that "...to stop traffic the officer should first extend his arm and index finger toward and look directly at the driver to be stopped" Rather, the guidance addresses the following major topics:

- Routing Guidance
- Scheduling Guidance
- Road Capacity Expansion
- Entry Control for Outbound Routes
- Perimeter Control on Inbound Routes
- Flow Maintenance
- Chain of Command
- Auxiliary Personnel and Equipment
- Priorities

For each topic, conventional, contingent, and contraproductive control measures are identified, the role of public safety personnel is outlined, and, where appropriate, personnel planning factors and duties are summarized.

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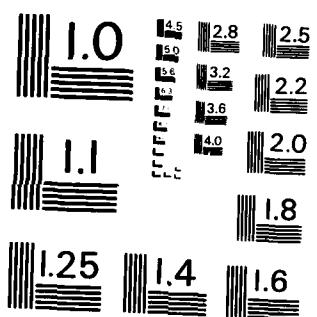
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PLANNING PHASE
TOPIC: ROUTING GUIDANCE
LEAD AGENCY: FEMA

SUMMARY OF TRAFFIC ROUTING MEASURES

1. CONVENTIONAL MEASURES

ALWAYS

- Use all available outbound roads
- Inspect all evacuation routes
 - during planning
 - prior to crisis relocation
- Balance flows to minimize clearance time
- Provide clear instructions
- Develop contingency plans to bypass potential bottlenecks

2. CONTINGENT MEASURES

If conventional measures prove inadequate, CONSIDER

- Revising host/risk assignments
- Redefining risk areas

3. CONTRAPRODUCTIVE MEASURES

AVOID

- Rigorous enforcement of individual route assignments
- Forcing individuals with personal host-area destinations into conformance with public plans

PLANNING PHASED

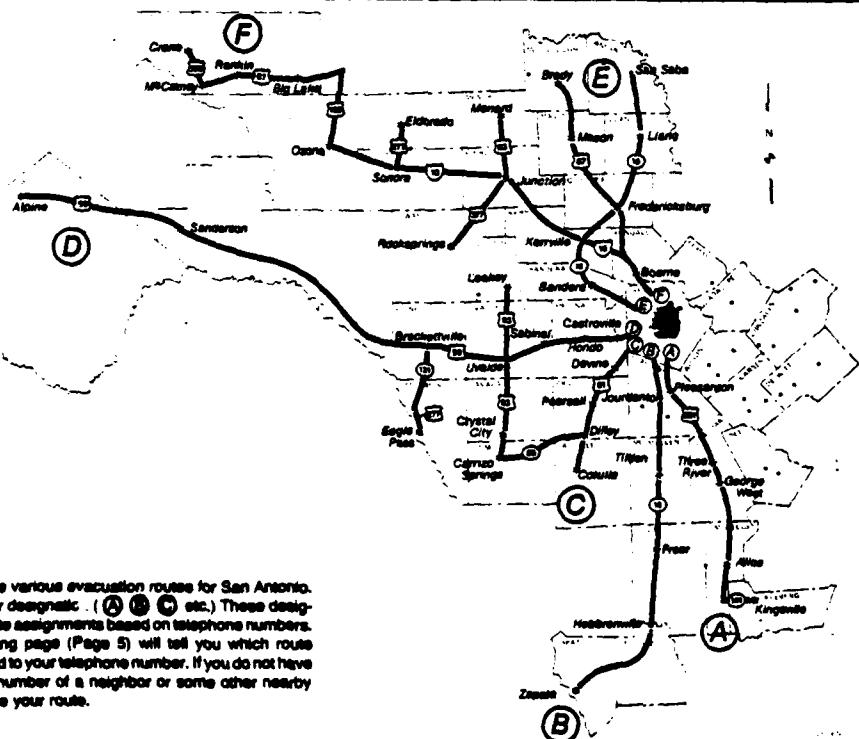
TOPIC: ROUTING GUIDANCE

LEAD AGENCY: FEMA

ROLE OF PUBLIC SAFETY PERSONNEL

- Assist in developing route assignments
- Participate in planning exercises
 - communications exercises
 - field exercises
- Inspect old evacuation routes
 - during planning
 - prior to crisis relocation
- Assist in developing contingency routing plans
- Review all routing plans periodically and be prepared to implement
- Use routing plans in developing personnel assignments for entry control, flow maintenance, and perimeter control

Exhibit: SAMPLE ROUTING GUIDANCE



This map shows all the various evacuation routes for San Antonio. Each route has a letter designation (A, B, C, etc.). These designations refer to the route assignments based on telephone numbers. The table on the facing page (Page 5) will tell you which route designation is assigned to your telephone number. If you do not have a telephone, use the number of a neighbor or some other nearby telephone to determine your route.

The table also identifies the highway you will take (e.g. US 281 south) and the assigned reception county and community. Your route is further identified on the simplified route maps given on Pages 6 and 7.

Sources: Reference 6-7

CRISIS RELOCATION ROUTE

PLANNING PHASE

TOPIC: SCHEDULING GUIDANCE

LEAD AGENCY: FEMA

SUMMARY OF TRAFFIC SCHEDULING MEASURES

1. CONVENTIONAL MEASURES

ALWAYS

- Broadcast information on traffic conditions
- Encourage off-peak departure times
- Operate support services around the clock
- Schedule departures of controllable groups
 - autoless residents
 - critical workers

2. CONTINGENT MEASURES

If conventional measures prove inadequate, CONSIDER

- Scheduling departures of different geographic regions at different times.
 - Begin with most densely populated section
 - Work outward toward host areas

3. CONTRAPRODUCTIVE MEASURES

AVOID

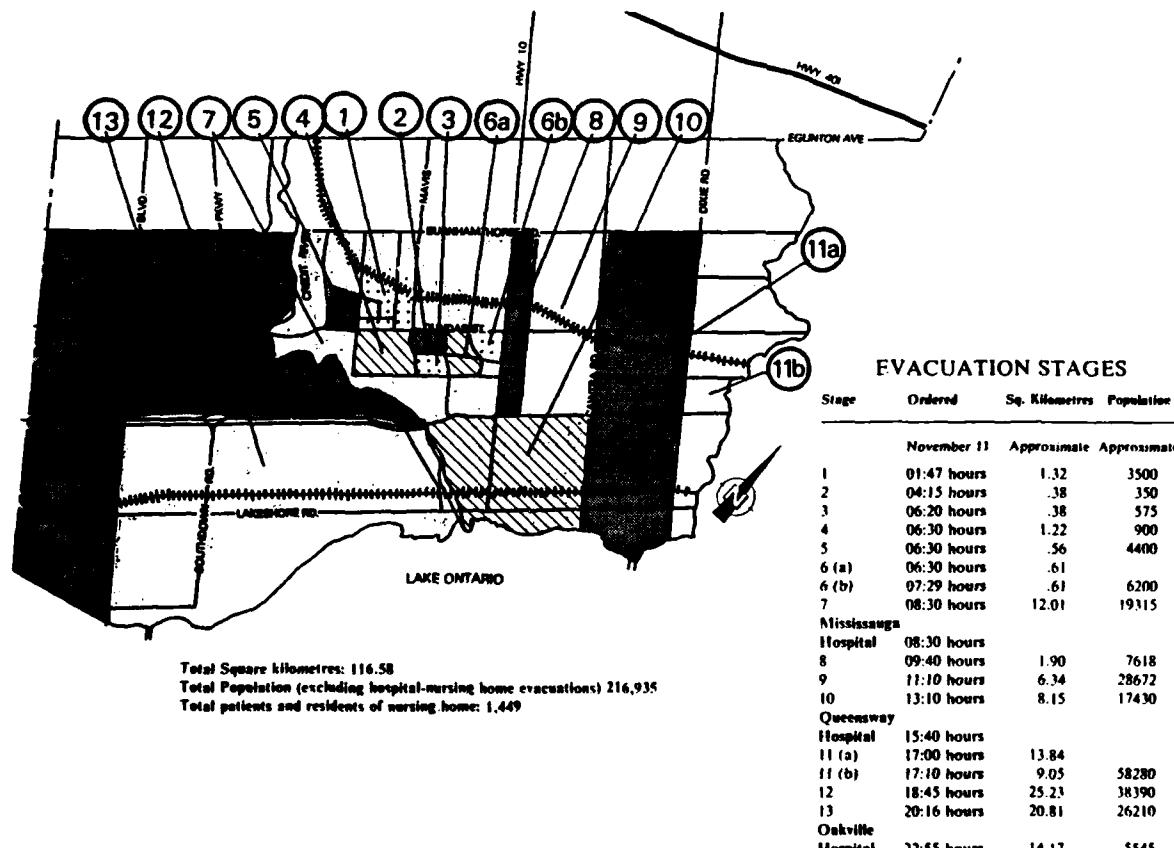
- Arbitrary scheduling rules (i.e. even/odd license plates)
- Scheduling departures during relatively short time intervals (i.e. hour-by-hour)
- Scheduling rules requiring individual vehicle inspection

PLANNING PHASE
TOPIC: SCHEDULING GUIDANCE
LEAD AGENCY: FEMA

ROLE OF PUBLIC SAFETY PERSONNEL

- Assist in developing departing schedules
- Participate in planning exercises
 - communications exercises
 - field exercises
- Review all departure schedules periodically and be prepared to implement
- Use scheduling plans in developing personnel assignments for entry control, flow maintenance, and perimeter control

Exhibit: SHOWING SCHEDULED STAGES IN MISSISSAUGA EVACUATION



Source: Reference D-1

IMPLEMENTATION PHASE
TOPIC: CAPACITY EXPANSION
LEAD AGENCY: TRANSPORTATION
OR HIGHWAY DEPARTMENT

SUMMARY OF CAPACITY EXPANSION MEASURES

1. CONVENTIONAL MEASURES

ALWAYS

- Make maximum use of shoulders
- Post adequate signs for traffic control
- Adjust signal timing to favor outbound traffic
- Encourage "first-auto" use

2. CONTINGENT MEASURES

If conventional measures prove inadequate, CONSIDER

- Establishing wrong-way flow on inbound routes
- Adopting vehicle occupancy restrictions on such separate rights-of-way as bus lanes and carpool lanes

IMPLEMENTATION PHASE

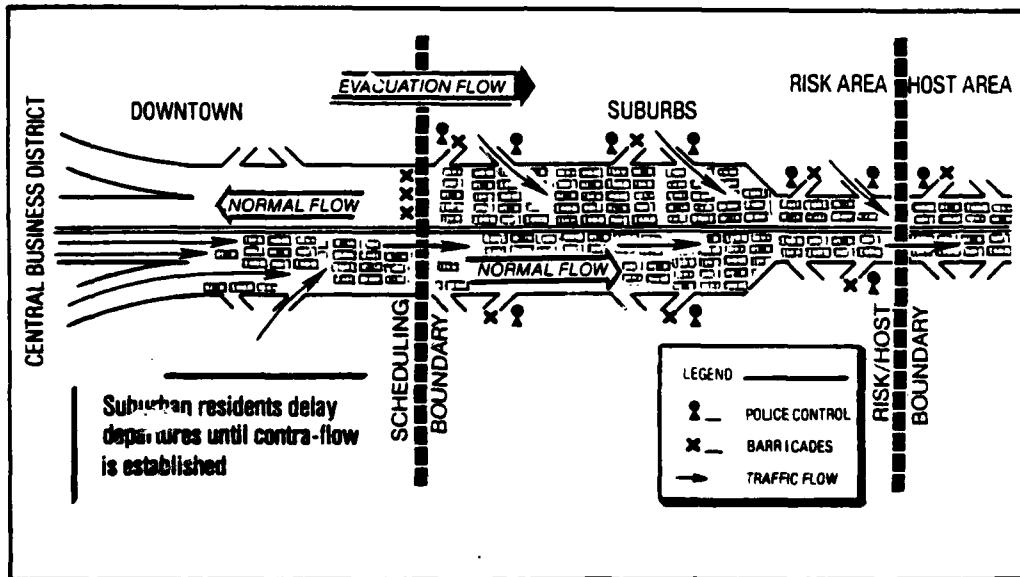
TOPIC: CAPACITY EXPANSION

LEAD AGENCY: TRANSPORTATION OR HIGHWAY DEPARTMENT

ROLE OF PUBLIC SAFETY PERSONNEL

- Permit use of shoulder lanes when merging problems can be avoided
- Obtain duplicate keys to signal boxes along evacuation routes
- Monitor sign placement
- Participate in planning and implementation of wrong-way flow measures
 - Clear traffic along inbound routes designated for reverse flow
 - Staff barricades preventing further entry of inbound traffic
 - Direct traffic into reverse-flow freeways

Exhibit: SAMPLE CONTRA-FLOW SCHEDULING



CONTROL PHASE

TOPIC: ENTRY CONTROL FOR OUTBOUND ROUTES

LEAD AGENCY: PUBLIC SAFETY AGENCY

SUMMARY OF ENTRY CONTROL MEASURES

1. CONVENTIONAL MEASURES

ALWAYS

- Identify key traffic control points
- Establish passive barricades using heavy equipment at controlled freeway ramps and intersections where access to outbound routes is to be cut off. Monitor with aerial surveillance.
- Assign traffic control officers to key intersections where streams of outbound traffic merge.

2. CONTINGENT MEASURES

If conventional measures prove inadequate, CONSIDER

- Stationing police officers at barricades
- Using police officers to meter flow onto freeway exit routes.

3. CONTRAPRODUCTIVE MEASURES

AVOID

- Moveable barricades (saw horses or cones)
- Permit systems requiring individual vehicle inspection in outbound traffic streams
- Denying access to individuals with personal host-area destinations which do not conform with public assignments

CONTROL PHASE

TOPIC: ENTRY CONTROL FOR OUTBOUND ROUTES

LEAD AGENCY: PUBLIC SAFETY AGENCY

ROLE OF PUBLIC SAFETY PERSONNEL

- Identify key control intersections and critical freeway ramps
- Prepare maps listing key entry control points
- Make sure resources for barricades are available and pre-position where possible
- Assist in placing barricades
- Retain control of keys to heavy equipment used as barricades
- Maintain aerial surveillance of unmanned barricades
- Assign traffic control officers to key intersections, manned barricades, and metered freeway ramps

PERSONNEL PLANNING FACTORS AND DUTIES

- Assign officers in teams of two to key intersections.* One officer will direct traffic while the other monitors flow conditions. Officers should switch roles every two hours
- Duties of the two officers are outlined below:

TRAFFIC DIRECTION OFFICERS

Promote orderly flow of vehicles by

- Directing evacuating vehicles through the intersection
- Controlling turning movements
- Clearing tie-ups
- Preventing movements not permitted by evacuation plan

Direct all vehicles through the intersection
DO NOT tie up traffic by

- Assisting individuals seeking information
- Stopping autos with windshield stickers indicating they are on the wrong evacuation route

TRAFFIC MONITORING OFFICER

Monitor traffic conditions by

- Keeping a general count of vehicles and occupants moving through the intersection (sample at intervals)
- Reporting count and general intersection status to EOC every 30 minutes
- Reporting serious problems as they arise
- Receiving and transmitting EOC instructions

Assist intersection officers in difficult situations

Monitor non-highway situation in immediate vicinity

Regain physical strength for the next 2 hours of intersection duty

*Complex intersections or particularly busy intersections may require additional teams of two officers.

CONTROL PHASE

TOPIC: PERIMETER CONTROL ON

INBOUND ROUTES

LEAD AGENCY: PUBLIC SAFETY AGENCY

SUMMARY OF PERIMETER CONTROL MEASURES

ALWAYS

- Establish control posts on all inbound routes
 - at outskirts of host area (early days of evacuation only)
 - at host-area/risk-area boundary
- Lay out ample traffic holding areas adjacent to control posts
- Intercept and interrogate all inbound traffic. Vehicles arriving at the outlying control points may
 - Proceed to risk area (if they have permits)
 - Obtain a permit and proceed to risk area
 - Be directed around the risk area
 - Return to their origin
 - Proceed to nearby host area

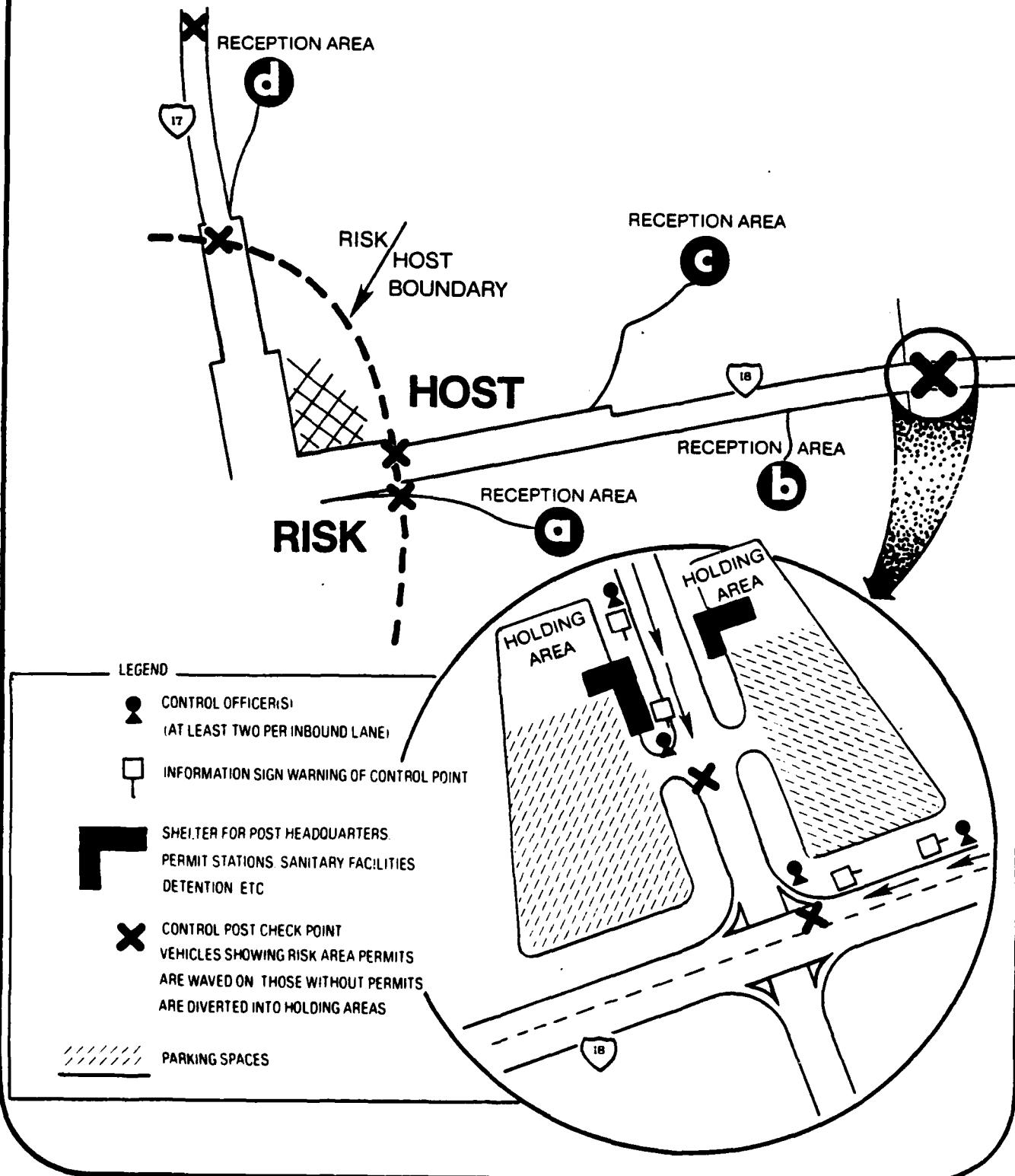
ROLE OF PUBLIC SAFETY PERSONNEL*

- Select control post locations on all inbound routes
 - at outskirts of host area
 - at risk/host boundary
- Lay out adjacent holding areas
- Prepare maps of control post locations
- Intercept and interrogate all inbound traffic
 - Allow permit holders to pass
 - Oversee permit-issuing stations at each inbound control post
 - Promulgate guidelines for issuing entry permits
- Patrol perimeter of risk area to discourage illegal re-entry
- Assign officers and auxiliary personnel to each control post

PERSONNEL PLANNING FACTORS

- Assign two officers per inbound traffic lane (Three may be needed in early stages on heavily-traveled lanes)
- Assign the additional officers per route to warn oncoming traffic of end of queue
- Assign one supervising officer per control post to oversee parking permit issuing and inspection activities

TYPICAL LOCATION AND LAYOUT OF PERIMETER CONTROL POST



CONTROL PHASE

TOPIC: FLOW MAINTENANCE

LEAD AGENCY: PUBLIC SAFETY AGENCY

SUMMARY OF FLOW MAINTENANCE MEASURES

- Dynamic Surveillance
- Routine Patrol
- Incident Response
- Destination Control

ROLE OF PUBLIC SAFETY PERSONNEL

- Prepare Deployment Plans for Personnel and Equipment
- Dynamic Surveillance
 - Establish liaison with Civil Air Patrol and Traffic Spotters units to augment surveillance staff as necessary
 - Maintain aerial surveillance of all traffic routes and key points
 - Station officers at key ground surveillance points
 - Prepare and transmit traffic advisory messages
 - Direct traffic onto detours in response to incidents, changing conditions, and traffic advisory messages
- Routine Patrol
 - Patrol all segments of evacuation routes, particularly potential bottlenecks
 - Carry gasoline for out-of-gas motorists
 - Assist stranded motorists and passengers
 - Apprehend motorists driving unsafely
- Incident Response
 - Develop alternative routing plans capable of bypassing congested bottlenecks
 - Respond to accident reports
 - Request tow trucks, motorist-aid units, and incident response teams as necessary
 - Clear stalled and disabled vehicles off evacuation roadways as soon as possible
 - Reinstate traffic flows once stoppage has been cleared
- Destination Control
 - Review host area parking plans to make sure ample parking is available
 - Direct vehicle flows to host area parking facilities
 - Supervise parking activities to keep queues from backing up onto evacuation routes

CONTROL PHASE
TOPIC: FLOW MAINTENANCE
LEAD AGENCY: PUBLIC SAFETY AGENCY

PERSONNEL PLANNING FACTORS

- **Patrol Duty: Equipment Assignments**
 - Use motorcycle units wherever possible
 - Assign one officer per patrol car
- **Patrol Duty: Beat Lengths**
 - Beat lengths along evacuation routes should not exceed 10 miles
 - a. Retain normal beat definitions within metropolitan areas
 - b. Shorten beat lengths along evacuation routes in rural areas
 - Patrol vehicles should pass each point on a beat
 - a. At least once every hour on bottleneck segments
 - b. At least once every two hours elsewhere
 - The following formulas may be used to compute personnel requirements and beat lengths

$$\text{Patrol Units Needed} = \frac{(\text{number of passes per 12-hour shift}) (\text{roadway length})}{6 (\text{average speed})}$$

$$\text{Beat Length} = \frac{6 (\text{average speed})}{(\text{number of passes per 12-hour shift})}$$

- **Destination Control**
 - Assign two officers to each host-area exit to keep exit traffic moving (*not to answer questions*)
 - Assign at least one traffic control officer to every major host-area parking lot.

ORGANIZATION

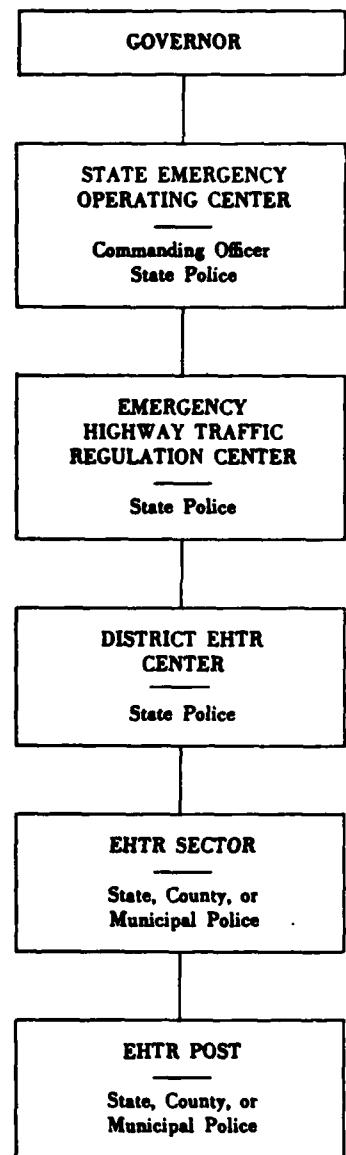
TOPIC: CHAIN OF COMMAND

Control at highways during emergencies requires the participation and close cooperation of state transportation agencies, state and local police organizations, and local highway/public works departments. In most states, the state transportation agency, or highway department, has been assigned responsibility for emergency highway traffic regulation. The authority for directing and enforcing these regulations is typically delegated to the commanding officer of the state police authority.

With this in mind, the Federal Highway Administration's *Guide for Highway Traffic Regulation in an Emergency* recommends the simplified chain-of-command at the right for assigning responsibility, delegating authority, and establishing lines of communication for emergency traffic control.

The following points should help to ensure the efficient functioning of such a chain-of-command in emergency situations.

- Because evacuation routes are likely to be state or federal highways crossing several county and municipal jurisdictions, state police agencies are the logical choice for the lead role in crisis relocation traffic control.
- For the duration of the evacuation, local public safety personnel should be employed insofar as possible in the vicinity of their jurisdictions, under the coordination and supervision of the State Highway Patrol Commander.
- To maintain an integrated field communications network:
 - Radio-equipped vehicles should not be assigned outside these normal operating areas
 - Forces assigned outside their own jurisdictions should be equipped with portable radios using local frequencies
 - Officers from other jurisdictions with incompatible frequencies should be paired with local officers
 - Field units involved in traffic control should maintain communications with their normal day-to-day communications center, which can retransmit messages as necessary
- Each state should establish current emergency communications links with contiguous state highway departments.
- Cooperation between different geographic jurisdictions should be pursued constantly through professional associations and law enforcement committee work.



ORGANIZATION TOPIC: PRIORITIES

Since the need for experienced police officers during crisis relocation is certain to exceed the number of local personnel available, it is absolutely essential that planners and area commanders set clear priorities on the tasks to be assigned under crisis relocation conditions. Priorities must be established locally to fit local conditions, but certain general principles should be observed:

1. Surveillance and control of bottleneck areas on outbound evacuation routes is of predominant importance. In addition, enough traffic control personnel must be assigned to host-area destinations to make sure that arriving traffic does not back up onto the evacuation routes.
2. The lowest order of priority should generally be assigned to traffic control on collector streets within the risk area. These streets will generally have sufficient capacity, and local congestion is not likely to affect the flow along critical outbound routes.
3. Perimeter control of inbound traffic is certain to be of less immediate importance than the maintenance of outbound flow. Some perimeter control tasks, such as driver interrogation and permit issuance, may be handled by volunteers or auxiliary personnel.

ORGANIZATION

TOPIC: AUXILIARY PERSONNEL AND EQUIPMENT

Public safety agencies will need to make intelligent use of volunteers and auxiliary personnel if crisis relocation is to succeed. While auxiliary personnel should be used sparingly in tasks requiring direct contact with evacuees under stressful situations (i.e. traffic control at evacuation route entry points within the risk area), they can help to relieve the pressure on public safety personnel in more controlled situations. Situations in which police departments might profitably use volunteer support for traffic control duties during crisis relocation include:

- Assistance with *host area* traffic control, particularly parking
- Administrative support for inbound checkpoints on the perimeter of risk and host areas (i.e., in issuing entry permits)
- Staffing of communications outposts
- Surveillance and communications support for on-duty traffic officers.

In order to make the most efficient use of volunteer personnel, public safety agencies should:

- Maintain lists of organizations and individuals capable of joining reserve units or mobilizing volunteer support
- Provide adequate training for the tasks assigned to auxiliary personnel
- Make sure that auxiliary personnel are issued proper identification
- Emphasize that auxiliary officers cannot exercise the powers of a police officer until they are given those powers by appropriate authority. Even then, powers should be limited by clearly defined restrictions
- Try to pair auxiliary personnel with experienced police officers
- Avoid placing auxiliary personnel in positions of direct confrontation with evacuating citizens
- Avoid planning to use persons who hold reserve positions in the military service or have other critical skills

ORGANIZATION

TOPIC: AUXILIARY PERSONNEL AND EQUIPMENT

Public safety personnel should maintain inventory of private resources which can be employed in a widespread emergency such as crisis relocation. Resources should be itemized as to type, location, method of contact, public use, limitations, accessibility, and other pertinent information. Such resources should include:

- Wreckers
- Heavy construction equipment and operators
- Aircraft for aerial surveillance
- Vehicle fuel and service outlets
- Motorcycle and car dealers
- Equipment service centers
- Communications equipment and amateur radio operators
- Motor fleet operators

Appendix B
INCIDENT RESPONSE MODELING

by
Juliet McNally

INCIDENT RESPONSE MODELING

Freeway incidents¹ are common occurrences in our normal daily lives. Under crisis relocation conditions, they are practically inevitable and may occur with higher frequency. In order to develop steps to minimize their adverse effects on traffic flow, quantitative understanding of the impacts of incidents on delay is essential. Based on the deterministic queueing model developed by Adolf D. May (Reference G-2), delay caused by an incident can now be estimated using mathematical models. The amount of congestion and delay following an incident is a function of a combination of factors (i.e., the capacity of the roadways, incident duration, demand and bottleneck flow rate).

Delay caused by incidents can be estimated by various measures, and the most commonly used are:

- Total delay in vehicle hours;
- Time for normal traffic flow to resume; and
- Maximum number of vehicles in the queue.

A simple blockage situation is used to illustrate (see Exhibit B-1) the steps in calculating the above measures. Readers who are interested in simulating more complex situations should consult Reference List F and G since computer programs have been developed and are available from various freeway incident management research organizations.

In this example, the in-lane incident has reduced the capacity of a four-lane freeway from 7,400 vehicles per hour to 4,300 vehicles per hour. If the incident had occurred on one shoulder of the freeway, the capacity reduction would have been smaller. Since under crisis relocation conditions, all roadways would be expected to operate at or near their capacity, the demand rate was set at 7,000 vehicles per hour. Under this set of circumstances, the 30-minute incident would have caused a total delay of 2,616 vehicle hours and congestion would have lasted for almost four hours (3.88 hours). At its peak, as much as 1,350 vehicles would have been held up by the incident. For this simple blockage situation, the time it takes for normal traffic flow to resume is almost eight times that of the incident duration.

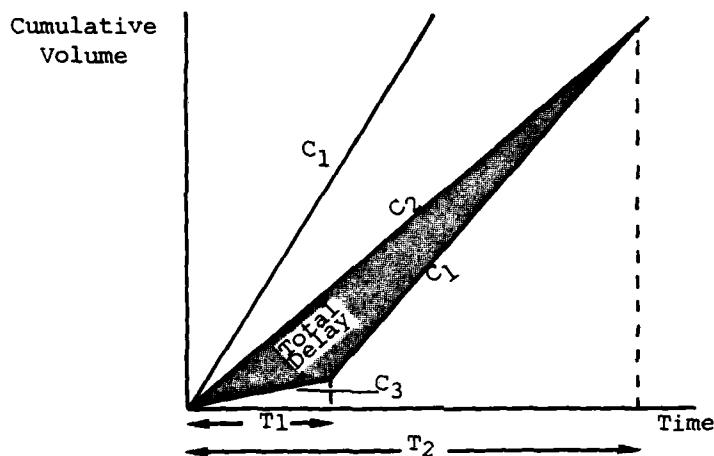
¹ "An incident is a spill, breakdown, accident, or any other extraordinary event that causes congestion and delay by restricting normal traffic flow." (Reference F-8, Vol. 1, p.1)

EXHIBIT B-1
SAMPLE INCIDENT RESPONSE CALCULATION

Example: An in-lane incident occurred on a 4-lane freeway, blocking traffic for 30 minutes. The demand rate was assumed to be constant throughout the incident.

IF $C_1=7400$ VPH
 $C_2=7000$ VPH
 $C_3=4300$ VPH
 $T_1=30$ minutes

WHERE:
 C_1 =Capacity of freeway
 C_2 =Demand
 C_3 =Bottleneck flow rate
 T_1 =Incident duration



$$\begin{aligned} \text{DELAY} &= \frac{T_1^2 (C_1 - C_3) (C_2 - C_3)}{2(C_1 - C_2)} \\ &= \frac{(.50)^2 (7400 - 4300) (7000 - 4300)}{2(7400 - 7000)} \\ &= 2,616 \text{ vehicle-hours} \end{aligned}$$

$$\begin{aligned} T_2 &= \frac{T_1(C_1 - C_3)}{C_1 - C_2} \\ &= \frac{.50(7400 - 4300)}{7400 - 7000} \\ &= 3.88 \text{ hours} \end{aligned}$$

$$\begin{aligned} Q_{\max} &= T_1 C_2 - T_1 C_3 \\ &= (.50)(7000) - (.50)(4300) \\ &= 1350 \text{ vehicles} \end{aligned}$$

Where Q_{\max} = Maximum number of vehicles in queue

Note: Details of the equations used in this example may be found in Reference F-2.

To minimize delay caused by an incident, one can alter the contributing factors, namely capacity, demand, incident duration and bottleneck flow rate. Since capacity of the roadway and bottleneck flow rate are usually not easy to change, we will concentrate on the impacts of varying incident duration and demand on delay. Using the same perimeters as the last example, the following table lists the resulting delay when the incident duration is decreased or increased by 15 minutes:

<u>Measures of Delay</u>	<u>Incident Duration Decreased to 15 Minutes</u>	<u>Incident Duration Increased to 45 Minutes</u>
Delay (vehicle hours)	654	2616
Time for Normal Flow to Resume (hours)	1.94	3.88
Maximum Vehicle in Queue	675	1960

From the table, we can tell that delay following an incident can be significantly altered by the incident duration. According to the queueing model and as shown in the above table, the increase or decrease of the time for normal flow to resume and the maximum queue length is in direct proportion to the increase or decrease of the incident duration, while the change in delay (in vehicle-hours) is proportional to the square of the increase/decrease of the incident duration.

Using the same parameters as the previous example, the following table lists the resulting delay when the demand at 30 minutes after the incident is decreased ranging from 15% to 50%.²

² Equations for calculating the delay measures for this condition can be found in Reference F-2.

Measures of Delay	Initial Demand Capacity	Decrease in Demand 30 Minutes After Incident			
		15%	25%	35%	50%
Delay (vehicle hours)	7,000	965	761	657	571
Time for Normal Flow to Resume (hours)	3.00	1.42	1.12	.97	.83
Maximum Vehicles in Queue	1350	1350	1350	1350	1350

Again, the figures indicate that a decrease in demand 30 minutes following the incident can alleviate the congestion problem significantly. In this example, even a decrease of 15% in demand can cut down the delay in vehicle-hours and time for normal flow to resume by almost threefold (2.7). However, if the initial demand is much lower than the capacity, the benefits from decreasing demand following an incident will be minimal. In this example, the demand (7,000 VPH) is set at near the capacity level (7,400 VPH), and therefore benefits more from the decrease in demand following the incident.

According to the queueing model, no queue or delay would be encountered until the demand exceeds the capacity level. In other words, if an incident occurs on a roadway where the demand is lower than the bottleneck flow rate following the incident, no queue or congestion will result. On the other hand, if an incident takes place at a bottleneck where the initial demand is greater than the capacity prior to the incident, the delay caused by the incident cannot be recovered. The only way to relieve such a situation is by decreasing demand (e.g., diverting traffic to alternate route, access control, etc.) following the incident and/or increasing the capacity of the bottleneck which is more difficult to accomplish. In summary, congestion caused by an accident can be reduced through a combination of traffic strategies that aim at reducing demand following the incident and/or reducing the time in clearing the incident.

Appendix C

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REFERENCES

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